SUMMER TRAINING PROJECT REPORT ON

DRIVE ELECTRONICS FOR GMRT SERVO SYSTEM

Completed At :-

GIANT METREWAVE RADIO TELESCOPE,
NATIONAL CENTRE FOR RADIO ASTROPHYSICS,
TATA INSTITUTE OF FUNDAMENTAL RESEARCH,
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CERTIFICATE

This is to certify that **Mr. Pritam Bhattacharjee** of Academy of Technology (WBUT, West Bengal) and **Ms. Pinal Bhansali** of P.V.P. Institute of Technology (Shivaji University, Maharashtra) has successfully completed the project on **"DRIVE ELECTRONICS FOR GMRT SERVO SYSTEM"** at the **GIANT METREWAVE RADIO TELESCOPE**, Khodad, Pune under my guidance.

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Last but not the least we would like to express our deep sense of gratitude to our parents and family for their constant support.

ABSTRACT

In this project we focus on the *drive electronics used in the GMRT servo system*. The GMRT servo system is responsible for the movement of all the 30 antennas of the GMRT. In this report we give detailed information about *DC servo motors*, basic *servo mechanism*, the *GMRT servo system*, *thyristor based half wave power control*, *servo amplifiers*, *mode selection* and also the process of *designing PCB using software*.

Two servo motors are required each for *Azimuth* and *Elevation*. Thus a total of 120 servo motors are used in the 30 antennas of GMRT. Of the 30 antennas, the antenna C-4 uses brush-less servo motor and the rest 29 antennas are currently using brushed servo motor. It is planned to replace the brushed motors with brush-less motors in all 30 antennas in the future.

In chapter 1, we give a *brief introduction about GMRT* including some *technical information*. Then we move on to chapter 2 which focuses on the *permanent magnet DC servo motors*, their *benefits* and *principle of operation*. These servo motors are used in GMRT. In chapter 3 we present the *DC servo mechanism*. Then in chapter 4, details about the *GMRT servo system* is provided. Chapter 5 includes the *thyristor based half wave power control*. In this chapter, first we explain s*ingle phase thyristor based half wave converter*, and then we explain the *three phase thyristor based half wave power control*. The three phase thyristor based half wave power control is what is used in GMRT. In chapter seven, we give details about the *servo amplifier*, its *specifications*, *features*, *advantages* and *disadvantages*. We also explain the *multi-axis three phase SCR servo amplifier*, which is used in the GMRT servo system. We also explain the theory of *operation of the servo amplifier* and give information about the various cards (pulse generator, motor control and so on) and devices used in the servo amplifier. We also present the *important amplifier parameters*. Next, in chapter 7 we describe the *equipments* used in the GMRT servo system. Chapter 8 explains the *operation of the GMRT servo system*. In chapter 9, we deal with *mode selection*. There are four modes, namely – *standby mode*, *remote mode*, *local mode* and *manual mode*. We give information about all the four modes. We also present the various commands that are used, followed by an explanation

of the *limit switches* that are used in the *AZ* and *EL* axes. In chapter 10, we explain the process of *designing PCB using software*. Here we design PCB for two of the cards used in the SCR servo amplifier: the *motor control card* and the *interlock & brake card*. We design the PCBs for these two cards using the software *Altium Designer*. Finally, in chapter 11, we present the *future scope* of our project and the future of the GMRT sevo system. In chapter 12, we give the *bibliography*.

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1. INTRODUCTION

BRIEF ABOUT GMRT :-

The **Giant Metrewave Radio Telescope (GMRT)** located at Khodad, 80 km north from Pune in India. It is the world's largest array of radio telescope at meter wavelength. It is operated by the **National Centre for Radio Astrophysics (NCRA)**, a part of the **Tata Institute of Fundamental Research(TIFR)**, Mumbai. A nearby town is Narayangaon on Pune – Nashik highway, 15 km from GMRT.

Fig1.1. *The GMRT array at centre square*

The GMRT consists of 30 fully steerable giant parabolic dishes of 45m diameter each spread over a distance of upto 25km. this is unique setup for astronomical research using metrewave length range of radio spectrum. At high frequencies the study of universe can easily be done. But in so high frequency RF noise is also high in other country, but in India this RF noise level is comparatively low. Thus it is one of the most challenging program to Indian scientists and engineers.

TECHNICAL INFORMATION :-

There are 14 telescopes randomly arranged in the central square, with a further 16 arranged in 3 arms of the nearly “Y” shaped array giving an informating baseline of about 25km. GMRT is an interferometer, uses a technique known as aperture synthesis to make image of radio sources.

Each antenna is of 45m diameter and insist of a solid surface like many radio telescopes, the reflector is made of wire rope stretched between metal struts in parabolic configuration. Each antenna has 4 different receivers mounted at the focus. Each individual receiver can rotate so that the user can select the frequency at which to observe. The array operated in six frequency bands centered on 50, 153, 233, 325, 610 and 1420 MHz. The construction of 30 large dishes at a relatively small cost has been possible due to an important technological breakthrough achieved by Indian Scientists and Engineers in the design of lightweight, low cost dishes. The design is based on what is being called the `SMART’ concept for Stretch Mesh Attached to Rope Trusses.

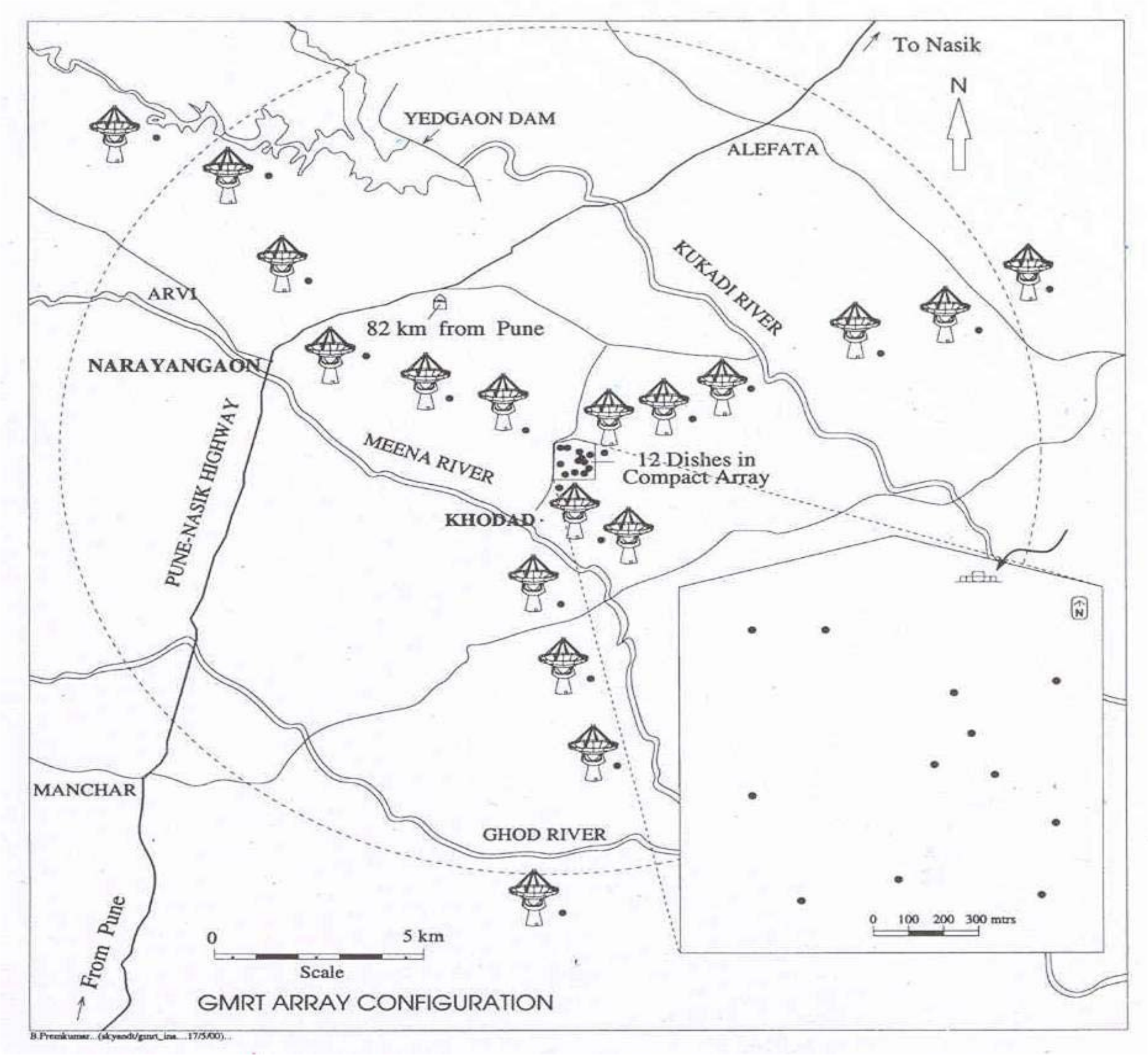


Fig1.2. *Locations of the GMRT antennas*

Why meter wavelengths : The meter wavelength part of the radio spectrum has been particularly chosen for study with GMRT because man-made radio interference is considerably lower in this part of the spectrum in India. Although there are many outstanding astrophysics problems which are best studied at meter wavelengths, there has, so far, been no large facility anywhere in the world to exploit this part of the spectrum for astrophysical research.

The Giant Metrewave Radio Telescope, an aperture synthesis array consisting of 30 fully steerable parabolic dishes of 45 meter diameter each. Motion of these giant antennas need to be controlled by a precession control system. Pointing of the antennas should be accurate i.e. the radio source, antenna focused and the antenna center should be aligned. The GMRT servo system has designed with three nested control loops to achieve the pointing accuracy of (1 or 2) arc mi nites RMS for wind speed less than 20 km/hr. Because of high weight alt-azimuth mount is most favorable approach for positioning the dish antenna. Here the elevation axis sits on the azimuth drive. The elevation drive moves antenna up and down directions while azimuth drive moves antenna in clockwise & counter-clockwise direction. Hence enabling the antenna to point anywhere in the sky.

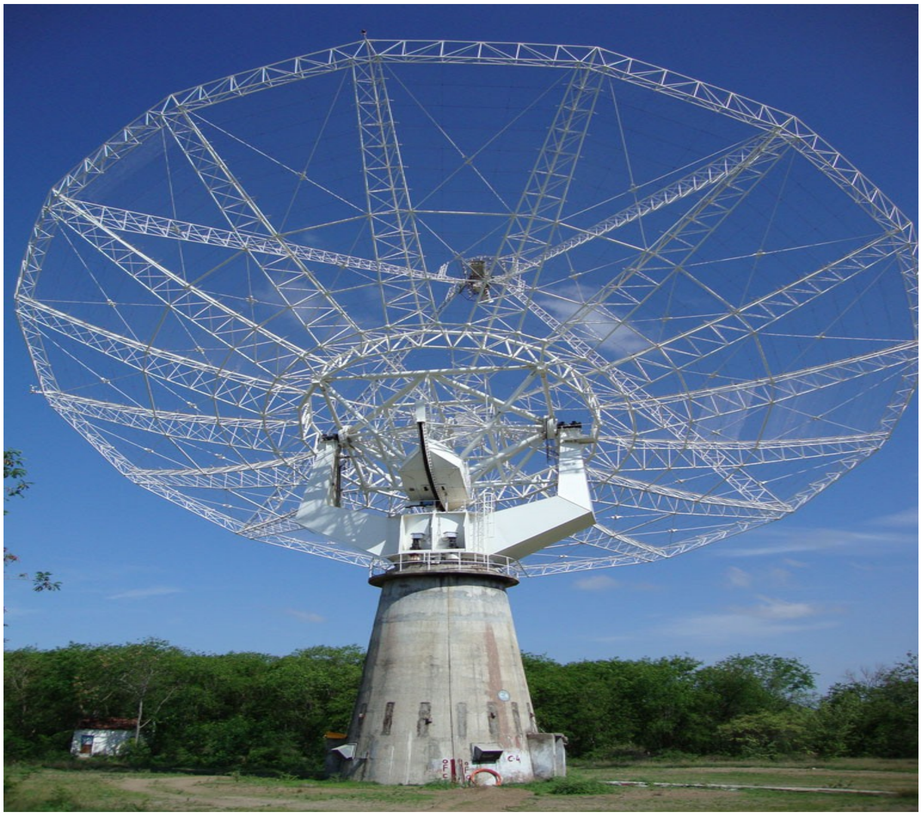


Fig1.3. *A GMRT antenna*

In GMRT there are total 30 antennas and each antenna consists of four servo motors. Two for azimuth operation and two for elevation operation. The DC motor requires a periodic maintenance to prevent it from permanent damage. Thus in case of GMRT where a large number of these servo motors are used and they work constantly as GMRT is 24×7 observatory, it is a huge problem for maintenance all these 120 antennas periodically. This is costly as well as it takes a large time. GMRT antennas have 45m diameter and they observes the universe like Jupiter, Sun, Pulsar, Y rays and X rays sources. It also observes the near Galaxies, Supernova and cluster of galaxies at very high Radio Frequency ranges. These antennas specify for the ranges 40 – 1700 MHz. But in such high frequency noise level also creates problem for these brushed motors. In case of brush-less motor the RFI can be eliminated. For these reasons a great project is to replace all the brushed motor with the brush-less motors in all GMRT antennas.

2. PERMANENT MAGNET DC SERVO MOTORS

Fig2.1. *A permanent magnet DC servo motor*

BENEFITS OF PERMANENT MAGNET MOTOR TACHOMETERS :-

1. High torque-to-inertia ratio, that is rapid response (short electrical and mechanical time constant).
2. Smooth acceleration and deceleration

3. High efficiency (power utilization)
4. High zero speed continuous torque capability (long thermal time constant)
5. Small size and weight.
6. Totally enclosed
7. Normal convection cooling (forced air optional)
8. Shaft mounted tachometer (resolver, brake, encoder optional)
9. Long brush life
10. Zero to high speed operation, that is, wide speed range.

THEORY OF OPERATION :-

The operation of a DC motor is based on electromagnetic fields and the laws governing them.

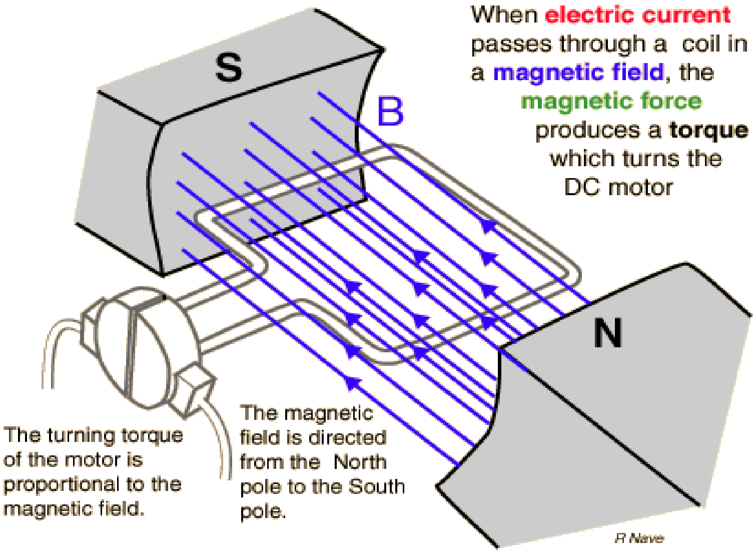


Fig2.2. *Magnetic field lines between north and south pole*

Passing current through a conductor (loop) creates magnetic force lines or flux. The number of these flux lines per unit area (flux density) is proportional to the magnetic force. If this conductor is placed at right angles to a magnetic field, forces add in such a way as to cause the loop to rotate.

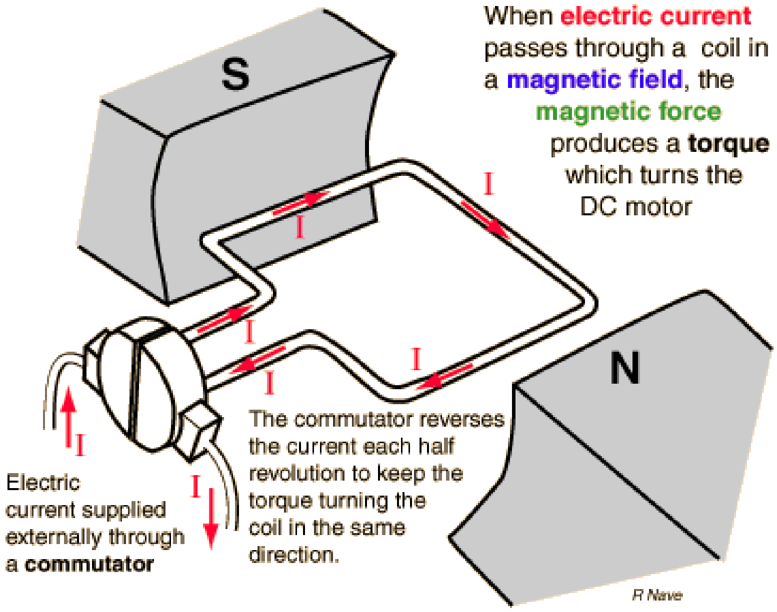


Fig2.3. *Current produced in magnets*

This is what causes a DC motor to rotate and develop torque, commonly called motor action. While the conductor is moving in this magnetic field, a voltage is generated across the conductor which is proportional to the flux density of the field and the length and velocity of the conductor. This is commonly called generator action.

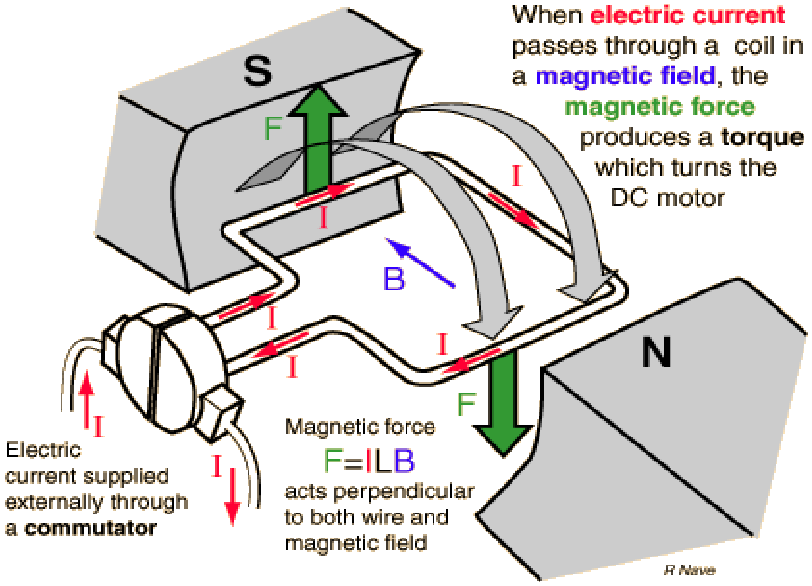


Fig2.4. *Force developed in magnets*

As the conductor lines up with the magnetic field the forces no longer cause the loop to rotate and the loop stops moving.

A DC motor includes an armature which contains many loops of conductors wound around the core of the motor shaft. Each loop is attached to a copper bar called a commutator segment. The commutator, an integral part of the armature, is a collection of these segments, and is used to distribute current to different loops via carbon brushes. Current is passed from a source through a stationary brush through a loop and flows out through another commutator segment and brush. Since the armature is located within a shell surrounded by permanent magnets, motor action occurs and the armature rotates. This movement brings another commutator segment onto contact with the brush and the process is repeated. As long as enough current is applied, the motor will continue to turn. By adjusting the voltage across the brushes, different speeds can be obtained.

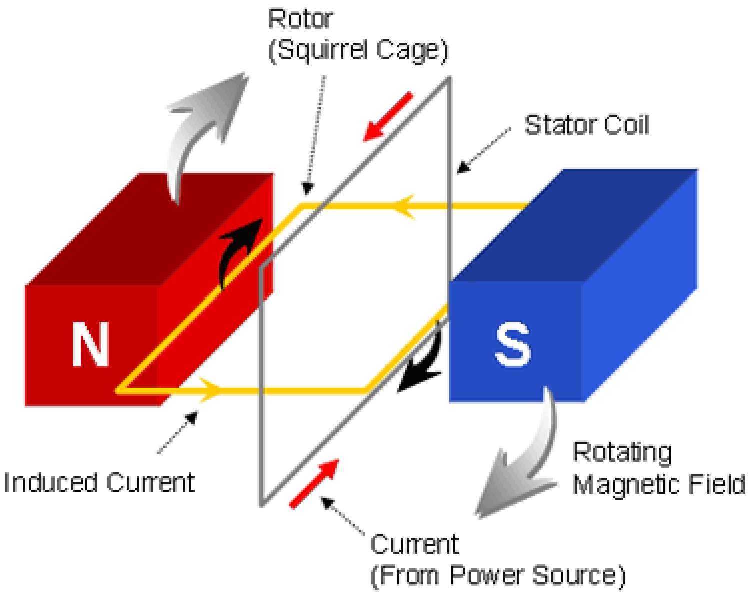


Fig2.5. *Rotation of the motor armature*

SERVO MAGNET TECHNOLOGY :-

A servo motor, capable of providing large continuous torque at zero speed, converts electrical voltage and current into a rotational mechanical movement using magnetic materials. The three most popular magnet materials are: ceramic, alnico and rare earth (samarium cobalt).

Ceramic magnets, the least expensive, have the lowest magnetic flux density which dictates that a larger package be used to provide given stall torque ratings.

Alnico has a higher magnetic flux density and allows the motor a greater stall torque rating for a given frame size. Also, the acceleration and peak torque ratings will be better than for ceramic magnet motors.

Samarium cobalt provides the highest magnetic flux density per unit of magnetic material and allows the greatest stall torque rating for a given motor frame size. The relative magnet energy of samarium cobalt is approximately 5.1 times greater then ceramic and 3.6 times greater than alnico. Therefore, higher peak torques are available allowing higher acceleration rates.

CONTINUOUS TORQUE AND HORSEPOWER :-

One of the prime features of a DC servo motor is its ability to provide high torque at zero speed. Therefore, the torque rating of a servo is usually given as a continuous stall rating. As the speed of the motor increases, the continuous torque drops until it intersects the continuous horsepower curve. At this point it follows the horsepower curve to top speed.

The commutating capability of the motor will determine its horsepower rating. A commutation level of 1.5 is usually considered the intermittent duty horsepower rating of the motor while a commutation level of 3 is considered the acceleration-deceleration horsepower limit.

BRUSH LIFE, COMMUTATION AND FLASH OVER :-

Brush life is a function of variables such as atmosphere, atmospheric pressure, humidity, brush composition, contamination, current and speed. In a relatively normal atmosphere brush life is given by

Brush life = {(Rated HP/Actual HP)^2} * (Brush life at rated HP)

Therefore, as actual HP increases, brush life drops by the square of that increase.

Of course, as HP increases about the continuous rating, the motor becomes thermally stressed. If HP becomes excessive and/or the brush area becomes contaminated, the air around the commutator becomes ionized and flash over will occur resulting in commutator damage. In some cases, the HP rating can be increased approximately 10 to 20 % by adding special brushes. The HP rating may also be increased by purging the motor with air to keep the ionizing gases away from the commutator. Brush life for operation of a motor continuously at its horsepower rating is 2000 hrs. For operation within the horsepower rating, brush life as high as 15000 hrs can be expected.

3. DC SERVO MECHANISM

A simple DC servo system consists of four major components. These are: a velocity command signal, a power amplifier, a motor, and a load. However, this system as described is seldom practical since it provides poor speed regulation under varying load conditions and no position control.

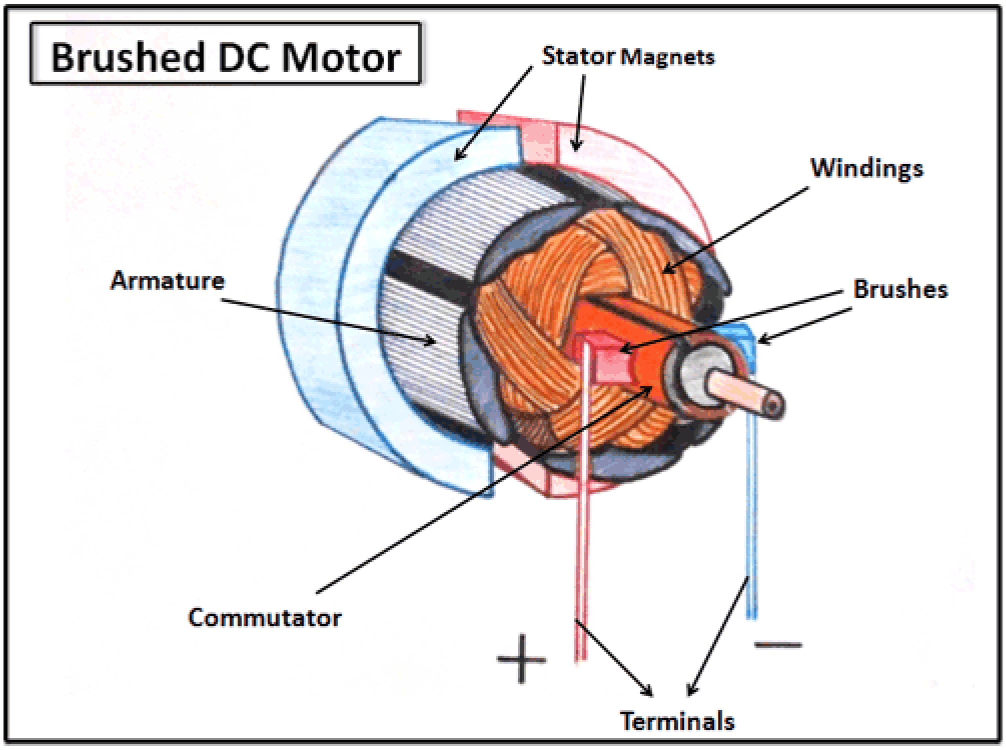


Fig3.1. *Brushed DC motor*

Speed regulation is accomplished by providing a velocity loop which includes the addition of a velocity feedback device, typically a tachometer, and a velocity controller. The velocity command signal is now compared with the tachometer feedback signal in the velocity controller and the resulting signal sent to the amplifier causes its output to vary if necessary thus maintaining constant motor speed.

Position control requires the addition of a position feedback device such as a resolver or encoder and a position controller to complete the position loop. The position signals from the feedback device are counted and compared with the position command signal resulting in a velocity command signal to properly locate the load.

FORCES IN A SERVO SYSTEM :-

There are two major categories of forces a motor has to overcome or provide in a servo system. First is the force required to accomplish the given task. This force is calculated by the machine designer according to his load criteria. The second category includes forces required to overcome frictional losses or to overcome uncounterbalanced weights in the system.

Frictional losses include static and dynamic losses in the motor, gear train losses and in the example of many machine tools, losses at the slide. If the motor is moving a slide in one of the horizontal axes (X or Y) it must overcome the frictional force of the slide which is the product of the slide weight and the coefficient of friction of the ways. In a vertical axis (Z) the force required to hold a slide against the ways (gib force) is multiplied by the coefficient of friction to determine that frictional force. Uncounterbalanced weights, if any, also appear in the vertical axis. It is important in a multi-axis machine to determine if one or more of the axes are carried by another axis thus increasing the effective slide weight.

All forces need to be summed at the motor to determine the torque it must develop. The forces given or calculated in pounds must be converted into torques and reflected through the gear train to the motor.

POSITION FEEDBACK DEVICES :-

Limit Switches: a simple switch which is set or reset mechanically. Limit switches are the least expensive and least accurate form of feedback. They are very easy to install in the position loop but can degrade motor brush life through severe commutation if not interfaced with a ramp generator function on the drive input.

Resolver: a transformer with a rotating secondary. A fundamental sine wave (usually 400 or 2500 Hz) is placed on the primary. As the secondary is turned, a sine wave appears with a phase shift from the fundamental which is proportional and sent to the computerized numerical control. Resolvers are rugged and noise immune. Cost is moderate, implementation is moderate, and accuracy is good. Resolvers are often mounted on the motor. However, increased accuracy is obtainable with the use of a precision instrument rack.

Incremental Encoders: optical devices which usually consists of a glass disc with an “A” channel, a “B” channel and a once around “marker”. Encoders interface easily to computers but are not as rugged or noise immune as resolvers. Their cost is moderate and accuracy is good.

Absolute Encoders: they are similar to incremental encoders except they have many channels which provide absolute positional information within 360 deg. They are usually more expensive than incremental encoders.

Inductosyn: a conductor of many hairpin turns (called a stator) is placed on a substrate and excited by a D.C. Voltage. A similar conductor with two separate conducting paths (called a rotor) is passed over the stator, resulting in two series of pulses with a 90 deg offset being sent from the rotor. Alternately, the rotor may be excited by equal-amplitude sinusoidal signals in time quadrature. The rotor output will then be a constant amplitude sine wave with a phase shift proportional to the position of the rotor. This is very much like a “linear” resolver. These devices are very accurate and more expensive than resolvers or encoders.

Glass Scale: similar to an encoder except it is a linear device. A glass rod is marked with a series of transparent and opaque areas. A light is shown through the windows and a sensor on the other side counts the number of times the beam is broken. These devices can be very accurate, but also very expensive.

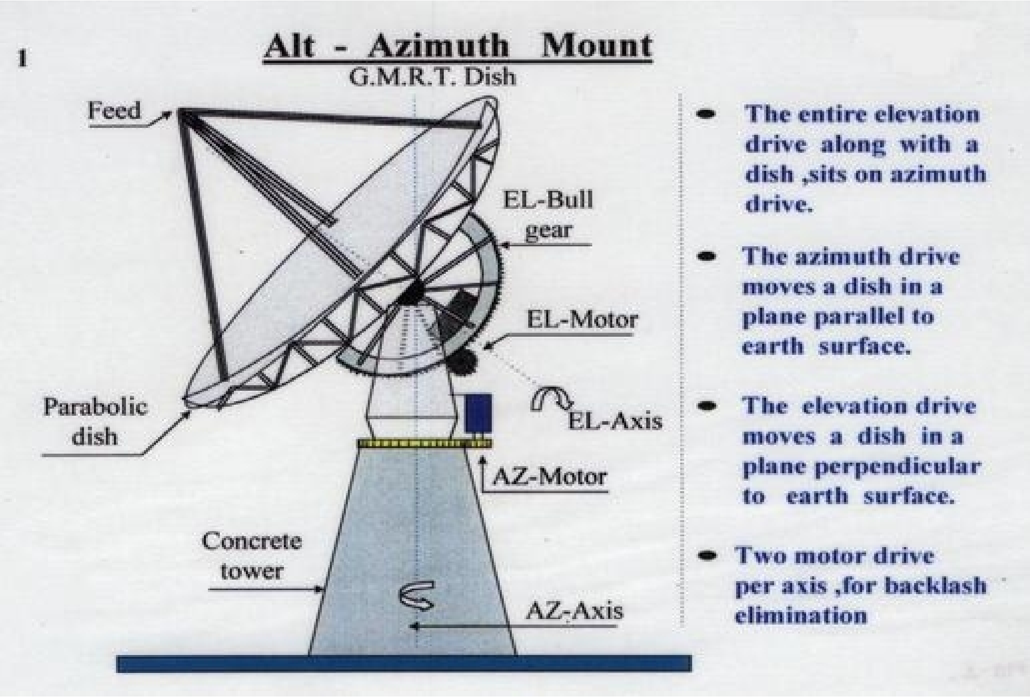
Laser Interferometer: it counts the wavelengths of light to determine position. It is the most accurate, most expensive and most difficult to implement form of position feedback.

POSITIONAL ACCURACY :-

Positional accuracy of a closed position loop servo system is primarily a function of the position feedback device and the position controller. If the position feedback device detects an error and the position controller supplies a 0.5 mV signal to the servo amplifier, the amplifier will integrate the signal, causing the motor to apply torque levels up to its peak rating to correct the error. Hence, system resolution is virtually the resolution of the feedback device.

4. THE GMRT SERVO SYSTEM

The Giant Metrewave Radio Telescope, an aperture synthesis array consisting of 30 fully steerable parabolic dishes of 45 metre diameter each. Motion of these giant antennas need to be controlled by a precession control system. Pointing of the antennas should be accurate i.e. the radio source, antenna focused and the antenna center should be aligned. The GMRT servo system has designed with three nested control loops to achieve the pointing accuracy of (1 or 2) arc minutes RMS for wind speed less than 20 kmph. Because of high weight alt-azimuth mount is most favourable approach for positioning the dish antenna. Here the elevation axis sits on the azimuth drive. The elevation drive moves antenna up and down directions while azimuth drive moves antenna in clockwise & counter-clockwise direction. Hence enabling the antenna to point anywhere in the sky.



- The entire elevation drive along with a dish ,sits on azimuth drive.
- The azimuth drive moves a dish in a plane parallel to earth surface.
- The elevation drive moves a dish in a plane perpendicular to earth surface.
- Two motor drive per axis ,for backlash elimination

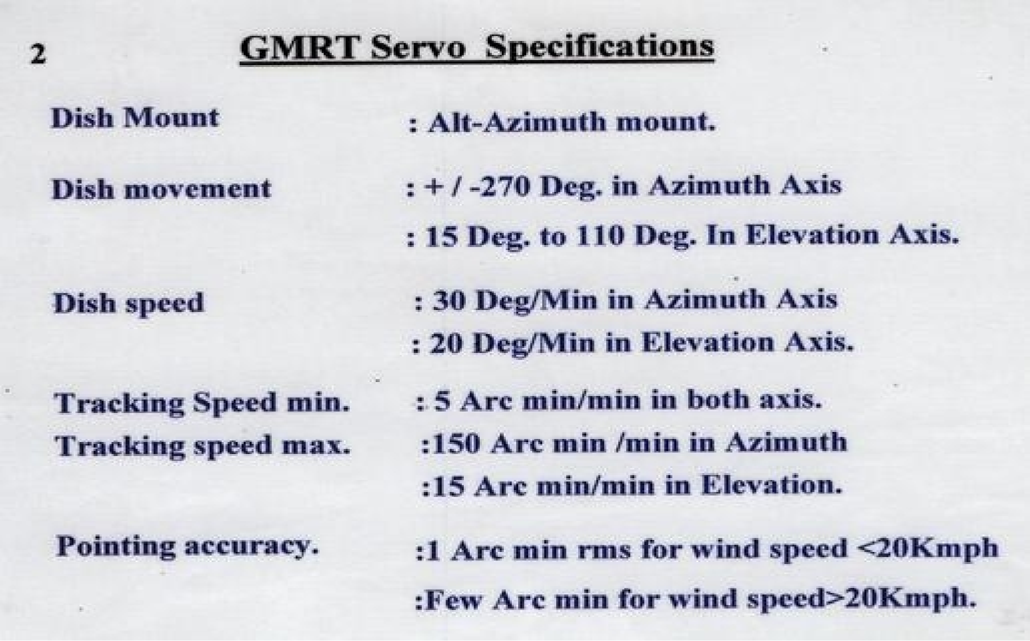
Fig4.1. *Alt-azimuth mount of GMRT antenna*

A servomechanism or servo is an automatic device that uses error sensing negative feedback to correct the performance of a mechanism. GMRT servo system, an example of such a servo mechanism, is designed to precision control the position of radio telescope while it is pointing to or tracking a source. It's also supposed to track an astronomical source with high accuracy along with maintaining stability of the heavy and flexible antenna system. This is achieved by rotating the antenna along two axes, azimuth and elevation axis, using a pair of motors for each axis. The position of the antenna is sensed using 17-bit absolute encoders and the source is tracked with a closed-loop servomechanism.

Servo motors being used in the current system of GMRT are Brushed DC motors. A major problem associated with these motors is the constant requirement of maintenance due to wear and tear of brushes, which leads to an increased down time along with the high maintenance cost. In order to overcome this problem, it is planned to replace the Brushed DC motors of GMRT antennas with the Brush less DC motors.

The servo amplifier is three phase, half wave, four quadrant, fully regenerative, SCR rate loop amplifier for the control of D.C. Servo motor. A rate loop amplifier is a device that maintains a speed proportional to a command input signal.

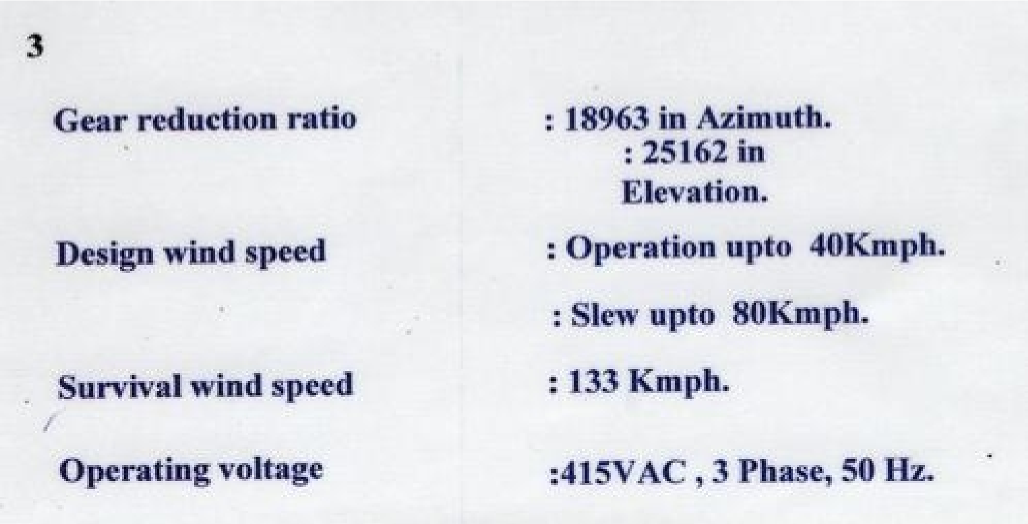
A unique approach to phase control and a full - time electronic current limiter assures excellent high speed commutation large life shortening first half cycle current pulses are eliminated. No vibration at null is produced as the quiescent [biased] current circulates through the inductor and not the motor armature circuit.



2 **GMRT Servo Specifications**

Dish Mount : Alt-Azimuth mount.
Dish movement : + / -270 Deg. in Azimuth Axis
: 15 Deg. to 110 Deg. In Elevation Axis.
Dish speed : 30 Deg/Min in Azimuth Axis
: 20 Deg/Min in Elevation Axis.
Tracking Speed min. : 5 Arc min/min in both axis.
Tracking speed max. :150 Arc min /min in Azimuth
:15 Arc min/min in Elevation.
Pointing accuracy. :1 Arc min rms for wind speed <20Kmph
:Few Arc min for wind speed>20Kmph.

Fig4.2a. *Specifications of GMRT servo system*



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Gear reduction ratio : 18963 in Azimuth.
: 25162 in Elevation.

Design wind speed : Operation upto 40Kmph.
: Slew upto 80Kmph.

Survival wind speed : 133 Kmph.

Operating voltage :415VAC , 3 Phase, 50 Hz.

Fig4.2b. *Specifications of GMRT servo system*

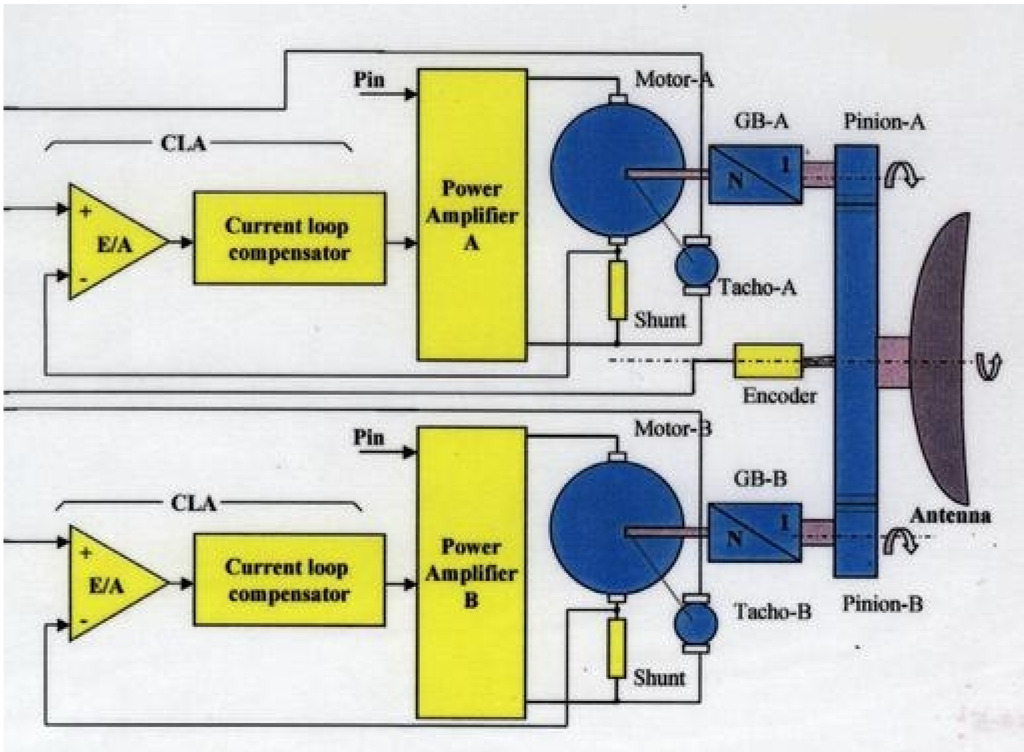


Fig4.3a. *Principle of position control*

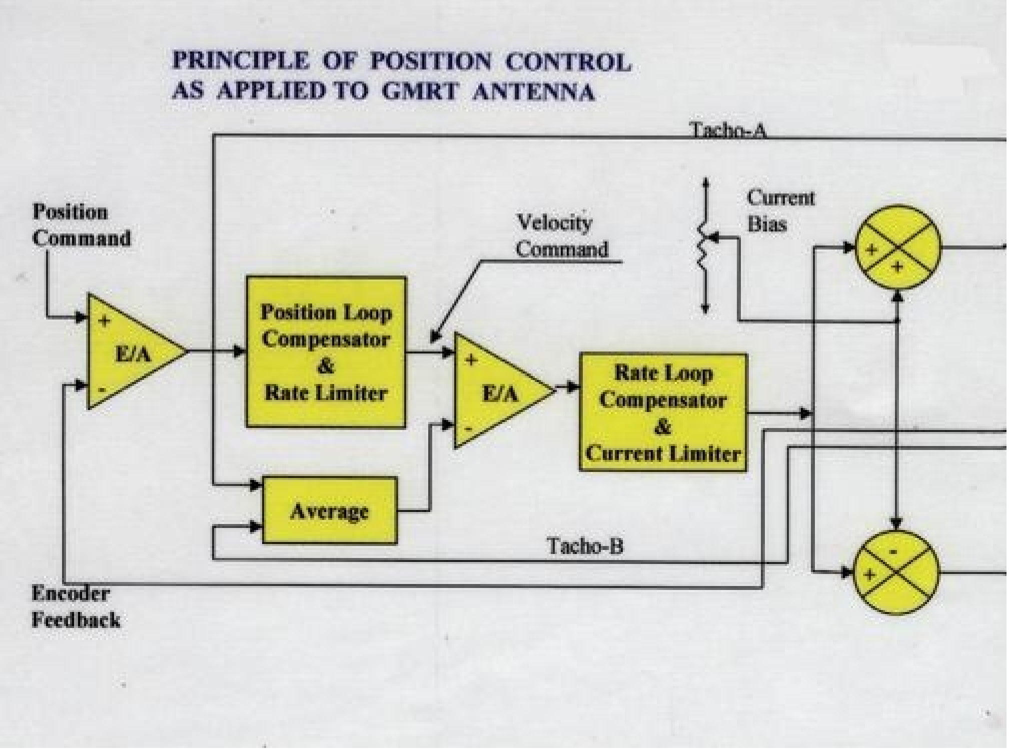


Fig4.3b. *Principle of position control*

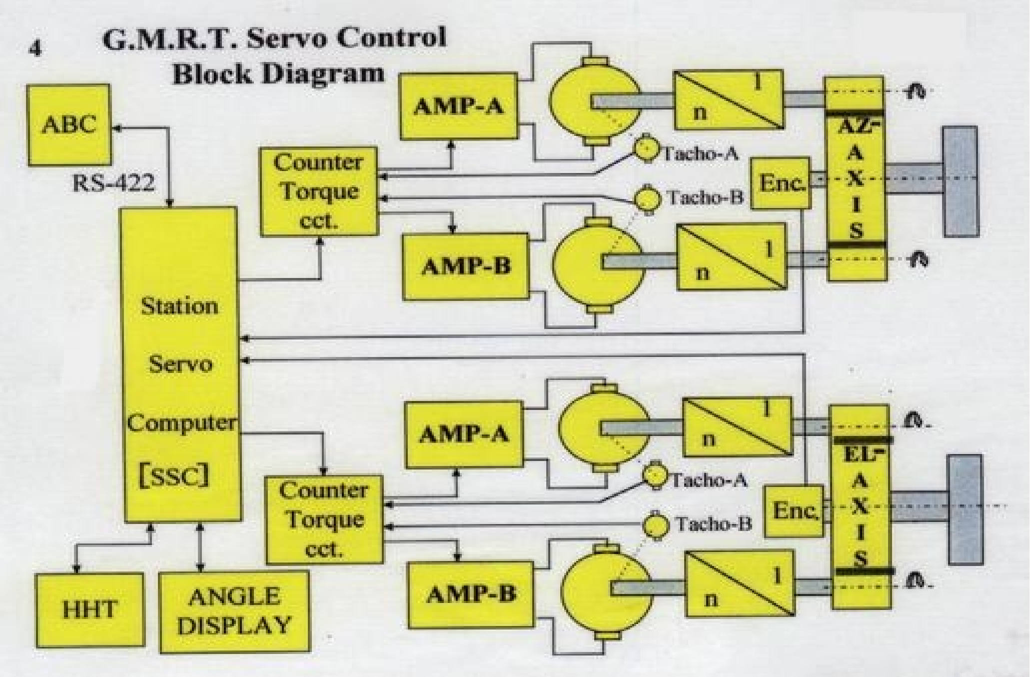


Fig4.4. *GMRT servo control block diagram*

The GMRT servo system constitutes the following three loops: position loop, velocity loop, current loop.

POSITION LOOP :-

A 17 bit absolute encoder senses instantaneous antenna position giving angular resolution of 10 arc sec. Desired position is fed to the servo computer by the master computer as required by the user. The servo computer consists of 8086 CPU based computer control system. It computes instantaneous position error every 100 msec and feeds it to compensator algorithm. The compensator algorithm implements a type I transfer function of the form

$$G2(s) = [G22(1+T21s)/s(1+T21s)]$$

The digital compensator uses Tustin transformation to transform above 's' domain transfer function to the 'z' domain. The corresponding difference equation is then solved in real time to implement the recursive filter. All the filter co-efficients are calculated online from the gain and time constants entered by the user. The gain and time constant values of the transfer function are entered during installation through a hand held terminal and are stored in EEPROM for non-volatility.

Within the position loop as formed within the servo computer, all computations are done using integer plus fraction representation. The angles are, therefore, represented as 16 bit integer (degrees) and 16 bit fraction (fractions of degrees). Numbers are internally scaled so as to optimally use the dynamic range of the number system. DAC of 16 bit resolution is used for achieving the required linearity.

VELOCITY LOOP :-

The velocity loop senses both the speeds and control averages of both the speeds. Speed feedback is derived from tachometers provided with servo motors. The tachos produce a DC voltage proportional to the motor speed. The velocity loop controller uses a lead lag compensator. The lead network is included in the tacho feed back path, boosts the low frequency forward gain necessary for good steady state accuracy. The output of the velocity loop serves as the common torque command to the both current loops. Two separate commands are generated by adding and subtracting a fixed DC bias from the common command.

CURRENT LOOP :-

The current loop consists of the current loop compensator, thyristor four quadrant convertor and DC servo motors. The current loop compensator consists of a PI controller giving a good steady state accuracy. The thyristor convertor consists of a fully controlled, three phase half wave, four quadrant, fully regenerative thyristor bridge. Four quadrant operation enables a motor to act as a generator thereby exerting an opposing torque in the counter torquing arrangement. Regenerative braking ensures quick reversal of motor.

The DC servo motor used is of permanent magnet type. It has high torque to inertia ratio which gives low electrical and mechanical time constants. Its large thermal time constant ensures high stall torque capacity necessary during very low speed tracking application.

The torque load encountered at the output shaft of the gear boxes consists of three major components: the wind forces on the dish, inertia torque for the dish rotation and friction torque on the support system of the dish. Continuous torque specified for loads at the output of the elevation gear box is 11000 Nm and 25400 Nm for azimuth at 40 kmph wind speed.

5. THYRISTOR BASED POWER CONTROL

THYRISTOR TURN-ON :-

A simple gating, or firing circuit, consists of a C-R circuit to control the time to build up a particular voltage across the capacitor, and a Diac which will break-over at a voltage, typically 20 to 60 V, depending on the type. When the break-over voltage is reached, voltage drop across the Diac will fall to about 1.5 V. In the given circuit, the thyristor will turn on at about Diac break-over.

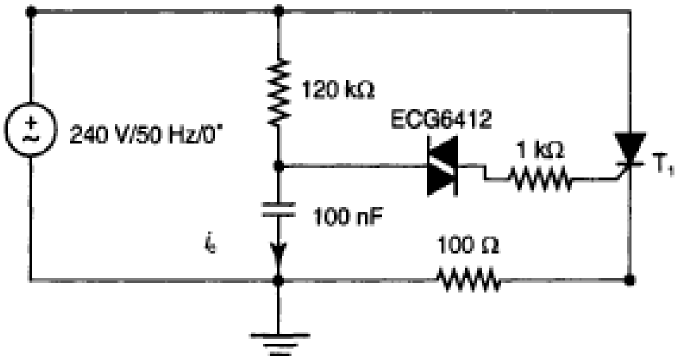


Fig5.1. *Thyristor firing circuit*

The Diac ECG6412 has a break-down, or switching voltage, of 63 V.

It can be shown that the current ic in the R-C circuit is given by the expression,

$$i_c = (E_m / |Z|)\ \sin(\omega t + \phi)$$

where,

$$|Z| = \sqrt{R^2 + X_c^2}$$

and

$$\phi = \tan^{-1}(X_c/R)$$

The capacitor voltage

$$v_c = i_c X_c$$

lagging the current by 90 deg.

$$X_c = 1/\omega C$$

$$v_c = (E_m X_c/|Z|)\ \sin(\omega t + \phi - 90^\circ)$$

SINGLE-PHASE HALF-WAVE CONTROLLED RECTIFIER :-

The simplest controlled rectifier uses a single device, such as a thyristor to produce variable voltage D.C. From fixed voltage A.C. Mains.

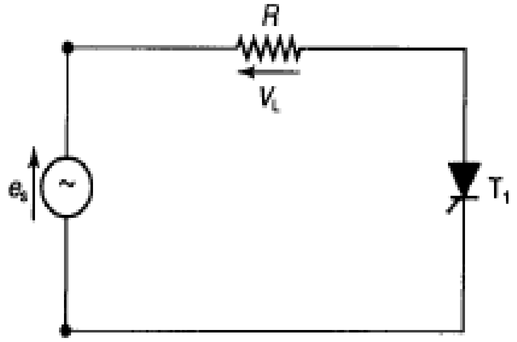


Fig5.2. *Single phase half wave SCR rectifier circuit*

In this arrangement,

$$e_s = E_m \sin \omega t = E_m \sin \theta = \sqrt{2}\ E_s \sin \theta$$

where Em and Es are the maximum and rms values of the supply voltage.

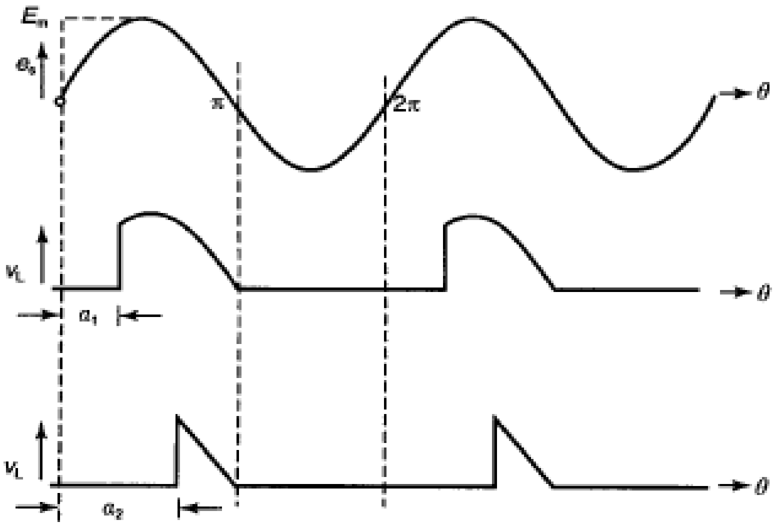


Fig5.3. *Single phase half wave SCR rectifier waveforms*

The thyristor is turned on in the positive half-cycle, some time after supply voltage zero, by the application of a gate pulse with delay angle α. In the negative half-cycle, the thyristor is reverse biased and cannot switch on. The larger the delay angle, the smaller is the average load voltage.

Average load voltage is found by calculating the area under the voltage curve then dividing by the length of the base. For any delay angle α, the average load voltage is given by

$$V_{av} = (1/2\pi) \int_{\alpha}^{\pi} E_m \sin\theta \, \delta\theta = (E_m/2\pi) \, [-\cos\theta]$$

Hence

$$\boxed{V_{av} = (E_m/2\pi)\,(1 + \cos\alpha)}$$

$$\boxed{I_{av} = V_{av}/R}$$

The square root of the average value of the square of the time-varying voltage gives the rms value:

$$V_{rms} = \sqrt{(1/2\pi) \int_{\alpha}^{\pi} (E_m \sin\theta)^2 \, \delta\theta}$$

Using the identity,

$$\sin^2\theta = 0.5(1 - \cos 2\theta)$$

$$V_{\text{rms}} = E_m \sqrt{(1/2\pi)\int_{\alpha}^{\pi} 0.5(1 - \cos 2\theta)\, \delta\theta}$$

$$= (E_m/2)\sqrt{(1/\pi)\,[\theta - (\sin 2\theta)/2]_{\alpha}^{\pi}}$$

$$= (E_m/2)\sqrt{(1/\pi)\,(\pi - \alpha + (\sin 2\alpha)/2)}$$

$$\boxed{V_{\text{rms}} = (E_m/2)\sqrt{(1 - \alpha/\pi + (\sin 2\alpha)/2\pi)}}$$

$$\boxed{I_{\text{rms}} = V_{\text{rms}}/R}$$

<u>THREE-PHASE HALF-WAVE SCR CONVERTER</u> :-

A source of balanced three phase star connected voltages is shown in fig. below:

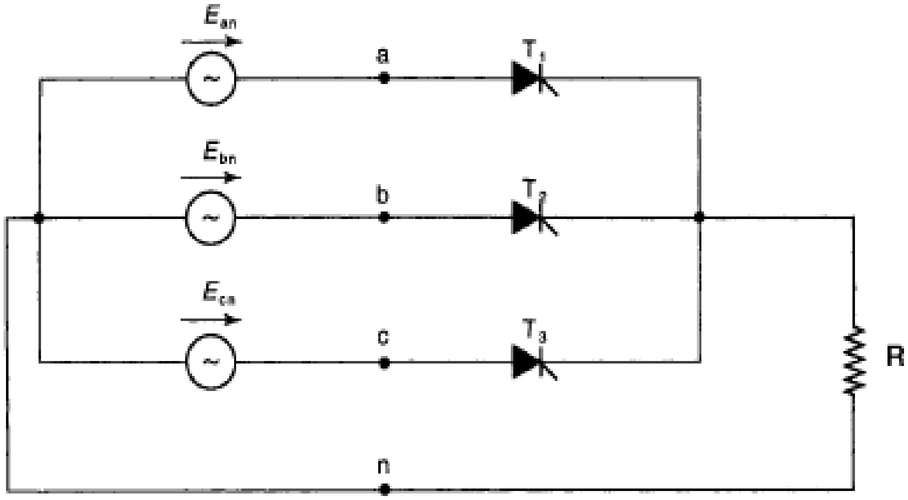


Fig5.4. *Three-phase half-wave SCR converter circuit*

Ean, Ebn and Ecn are the values of the rms phase voltages. Instantaneous phase voltages are given by the expressions:

$$e_{an} = E_{pm} \sin \omega t$$

$$e_{bn} = E_{pm} \sin (\omega t - 120°)$$

$$e_{cn} = E_{pm} \sin (\omega t - 240°) = E_{pm} \sin (\omega t + 120°)$$

where Epm is the maximum value of the phase voltage. The instantaneous values of the line voltages are given by,

$$e_{ab} = (e_{an} - e_{bn}) = \sqrt{3}\, E_{pm} \sin (\omega t + 30°) = E_{lm} \sin (\omega t + 30°)$$

$$e_{bc} = (e_{bn} - e_{cn}) = \sqrt{3}\, E_{pm} \sin (\omega t - 90°) = E_{lm} \sin (\omega t - 90°)$$

$$e_{ca} = (e_{cn} - e_{an}) = \sqrt{3}\, E_{pm} \sin (\omega t - 210°) = E_{lm} \sin (\omega t - 210°)$$

where Elm is the maximum value of line voltage.

The waveforms of the line and phase voltages are given in Figs. 5.5 and 5.6.

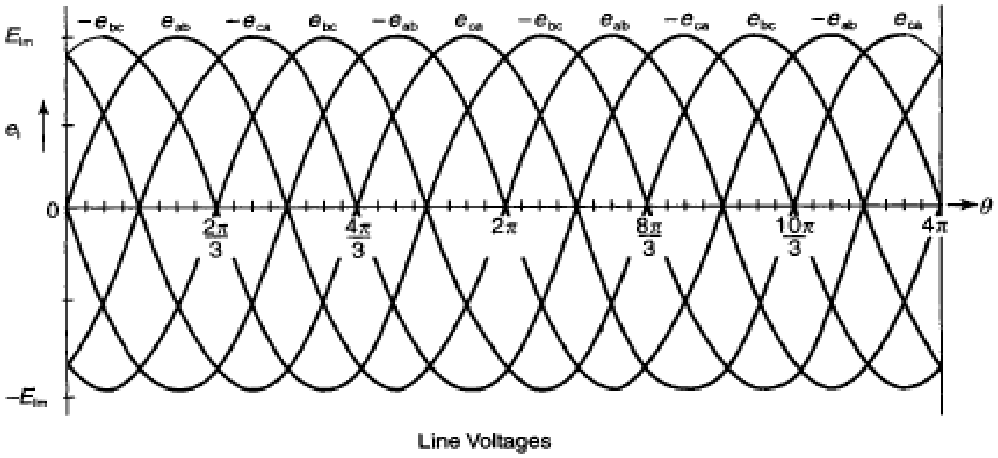


Fig5.5. *Line Voltages*

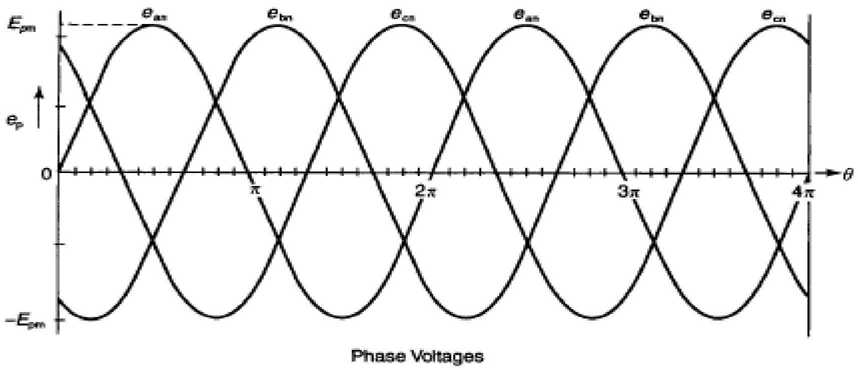


Fig5.6. *Phase Voltages*

The half-controlled converter thyristors switch the phase voltages. The thyristor only turn on when a gate pulse is received if the anode is positive with respect to the cathode. If T3 was conducting then T1 could be turned on just after the cross-over point of voltages e_{cn} and e_{an} at angle 30 ° or π/6 rad. The phase voltages are then 0.5Epm. When T1 turns on, T3 is reverse-biased by the phase voltage e_{an} and turns off. This process is called line commutation. The next cross-over point is at angle 150 ° or 5π/6 rad. T2 is turned on here, commutating T1.

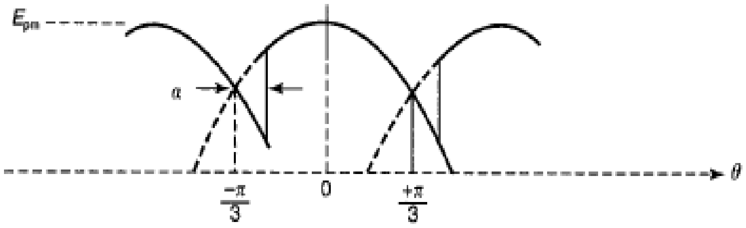


Fig5.7. *Waveform of the load voltages*

Average load voltage,

$$V_{av} = E_{pm}/(2\pi/3) \int_{-(\pi/3)+\alpha}^{(\pi/3)+\alpha} \cos\theta \, \delta\theta = 3\, E_{pm}/2\pi\, [\sin\theta]$$

$$= 3\, E_{pm}/2\pi \,\{ \sin(\pi/3 + \alpha) - \sin(-\pi/3 + \alpha) \}$$

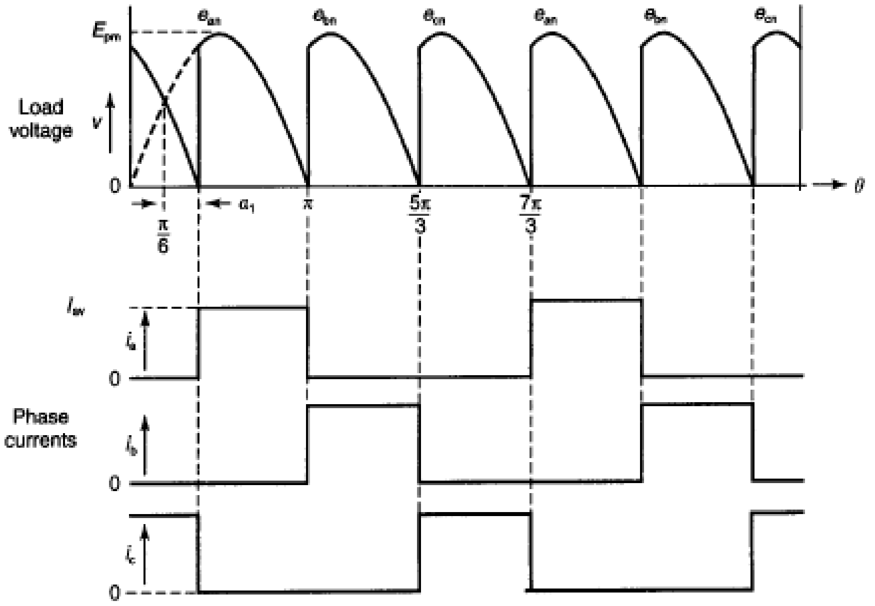
$$= 3\, E_{lpm}/\pi \,\{\sin(\pi/3) \cos\alpha + \cos(\pi/3) \sin\alpha - \sin(-\pi/3) \cos\alpha - \cos(-\pi/3) \sin\alpha\}$$

$$\boxed{V_{av} = 3\sqrt{3}(E_{pm}/2\pi) \cos\alpha = 0.827\, E_{pm} \cos\alpha}$$

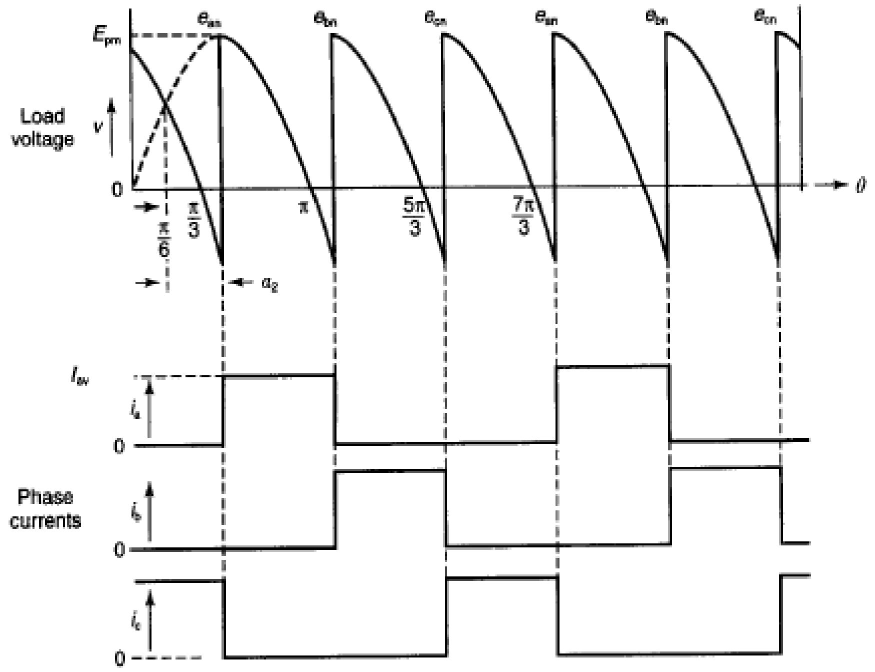
$$I_{av} = V_{av}/R$$

The phase current is Iav for a 120°period, and zero for two further 120°periods:

$$I_{rms} = \sqrt{(I_{av}{}^2 + 0 + 0)/3} = I_{av}/(\sqrt{3})$$



(a) Firing angle delay α_1



(b) Firing angle delay α_2 ($\alpha_2 > \alpha_1$)

Fig5.8. *Voltage and current waveforms*

Load power,

$$P = I_{av}^2 R$$

Converter power factor,

$$\cos\phi = P/3\ E_{rms}\ I_{rms}$$

Assuming that the a.c. supply to the converter is obtained from the secondary windings of a three phase transformer, then straight star connection as shown in Fig. 5.4 would not be suitable due to the d.c. component of the phase currents producing d.c. magnetizing ampere-turns in the transformer. This problem is overcome by using a zig-zag connected secondary winding which cancels out the d.c. ampere-turns in each phase.

SIX PULSE THYRISTOR CONVERTER :-

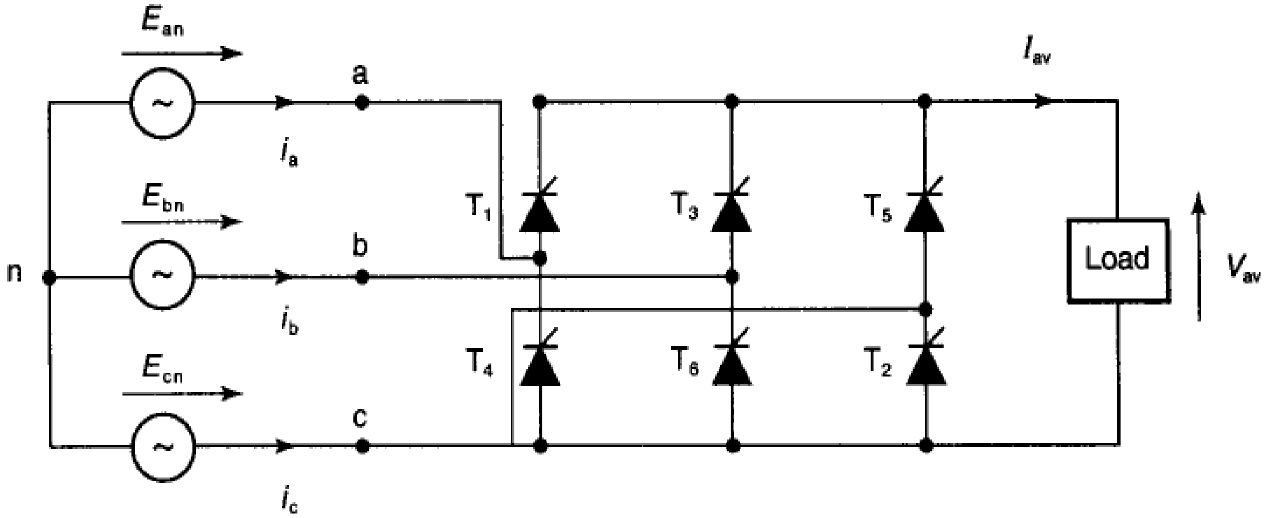


Fig5.9. *Six pulse thyristor converter*

In this circuit, two thyristors are fired simultaneously. The reference point for successful turn-on is now the cross-over of the line voltages. Firing pulses are required every 60 deg, or π/3 rad. Thyristors T1, T3 and T5 are referred to as the positive group; thyristors T4, T6 and T2 are the negative group. Each thyristor is conducting for a 120 deg period, and is off for a 240 deg period.

Fig5.10. shows the waveforms of line voltages, load voltage, thyristor currents and one line current for a firing angle delay α of about 30 deg.

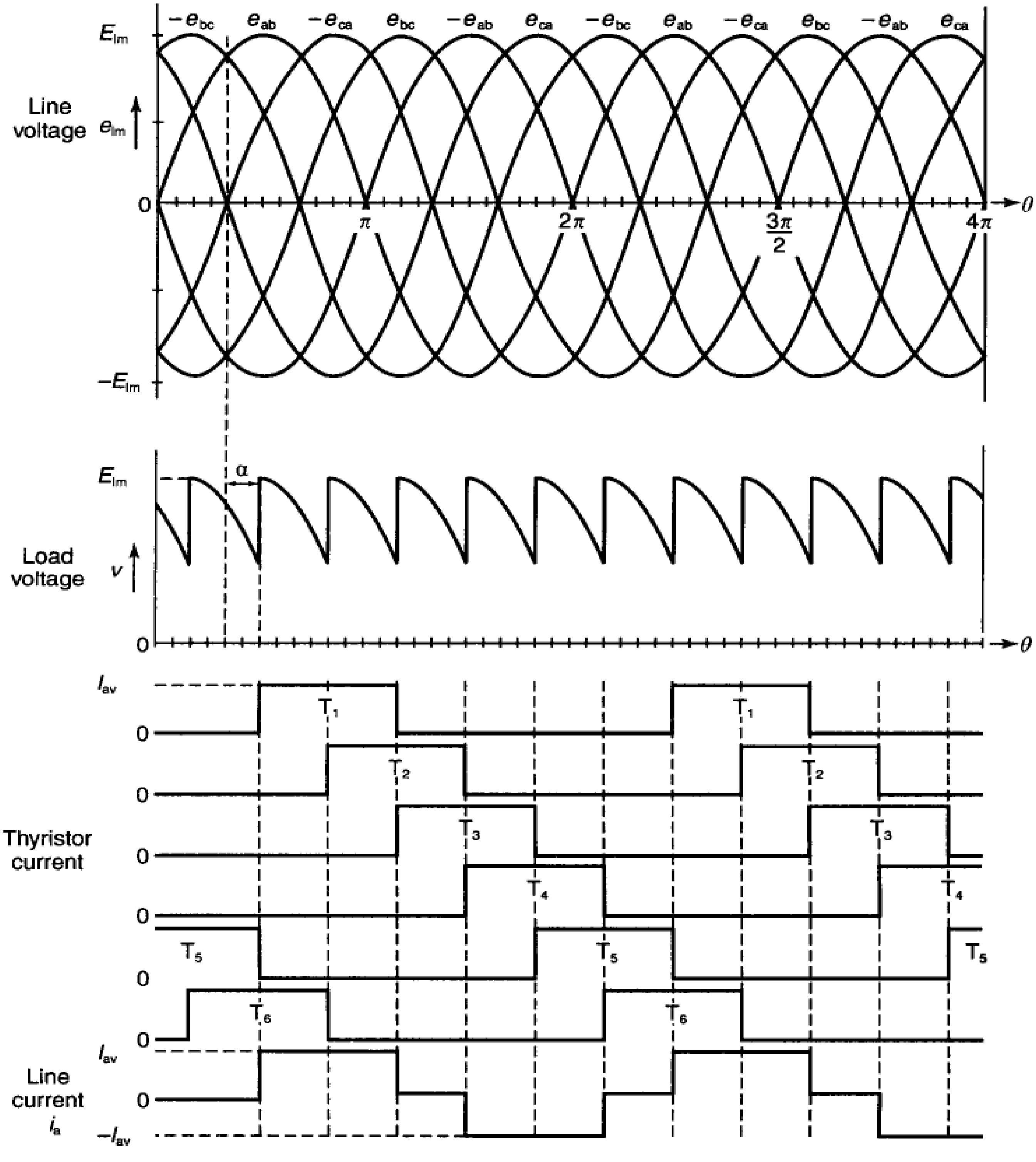


Fig5.10. *Six pulse converter waveforms*

Each firing period is symmetrical, and taking the reference point as line voltage maximum, the average load voltage is found as,

$$V_{av} = E_{lm}/(\pi/3) \int_{-(\pi/6)+a}^{(\pi/6)+a} \cos\theta \, \delta\theta = 3E_{lm}/\pi \, [\sin\theta]_{-\pi/6 \, + \, \propto}^{\pi/6 \, + \, \propto}$$

$$= 3\ E_{lm}/\pi \ \{ \sin(\pi/6 + a) - \sin(-\pi/6 + a) \}$$

$$= 3\ E_{lm}/\pi \ \{ \sin(\pi/6)\cos a + \cos(\pi/6)\sin a - \sin(-\pi/6)\cos a - \cos(\pi/6)\sin a \}$$

$$\boxed{V_{av} = 3(E_{lm}/\pi)\cos a = 3\sqrt{3}\,(E_{pm}/\pi)\cos a}$$

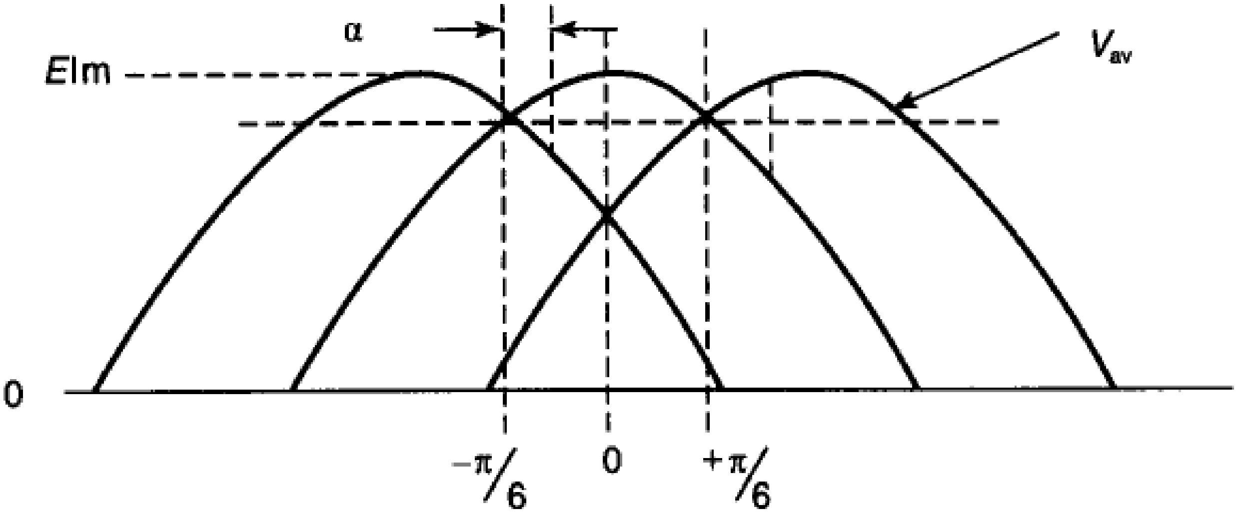


Fig5.11. *Waveform of the load voltage for a six pulse converter*

6. SERVO AMPLIFIER

Servo amplifiers are 4-quadrant, regenerative power amplifiers, supplying appropriate power to the motor as commanded by a control voltage. These amplifiers are capable of supplying energy to the load, as well as absorbing energy from the load. They are designed to convert the kinetic energy of the combined motor load, into electrical energy while the load is decelerating.

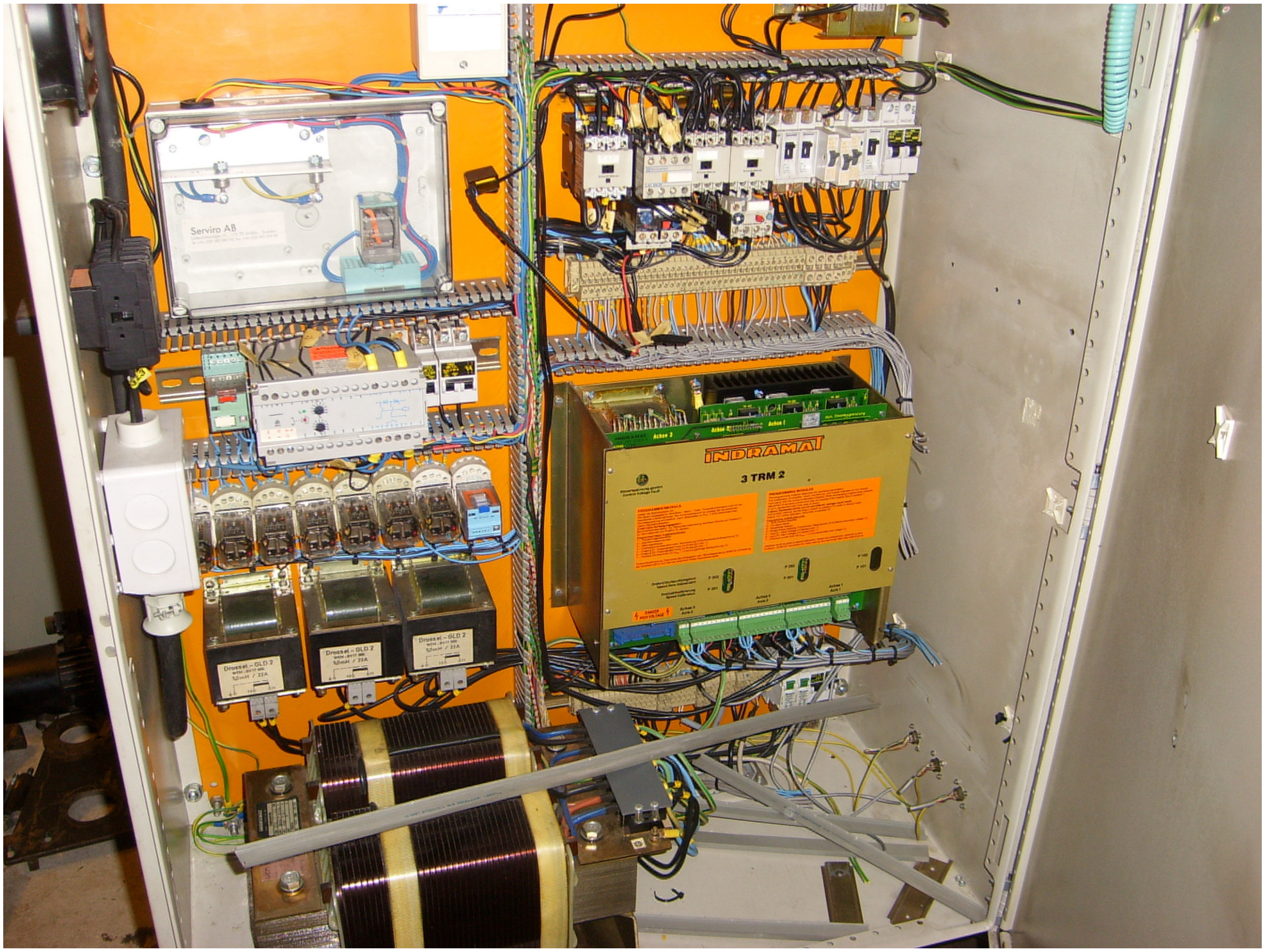


Fig6.1. *SCR servo amplifiers*

The GMRT servo amplifier is a three phase, half wave, four-quadrant, fully regenerative, SCR CLA for the control of permanent magnet DC brush type motors. A CLA is a device, which keeps the current through the motor proportional to a commanded input signal.

Type	3-Phase, SCR based, 4-quadrant fully regenerative.
Control Type	Phase angle control with current loop.
Input Volts	275VAC L-L, 50 Hz, 3-Phase, 4-wire.
Command Volts	+/- 10 Volt.
Maximum Current	+/- 80 Amp.
Protection	Over current & over speed.

Fig6.2. *Servo amplifier specifications*

The function of the amplifier is two fold :- firstly, it has to provide power to the motor so as to drive it in the required direction against the load and secondly, it has to regulate the motor speed in accordance with the input or reference signal, which is usually in the range of +/- 10 V.

TYPICAL AMPLIFIER FEATURES :-

- Low form factors
- Adjustable speed scale factors
- Zero offset adjustment
- Stability adjustment
- Integral rate feedback loop
- Proportional torque control
- Auxiliary output terminals
- Remote gate shut off
- Operational test capability
- Two stage current limit
- I^2 fusing
- Automatic overspeed shutdown

- Transient protection
- Phase insensitivity
- Temperature stability
- Fault ride thru operation
- Velocity feedback loop
- Static stiffness at zero speed
- Inhibit circuitry
- Slow blow fuses
- Swing away control section
- Direction limits
- Torque hold
- Amplifier enable

ADVANTAGES OF SCR SERVO AMPLIFIERS :-

- Lower unit cost
- High peak current capability
- High thermal reserve (operation above continuous current rating is possible for several minutes)

DISADVANTAGES OF SCR SERVO AMPLIFIERS :-

- High form factor
- High magnetic requirements

MULTI-AXIS 3 PHASE SCR SERVO AMPLIFIER :-

The Inland Motor TPA /1, /2 and /3 series are multi-axis, three phase, half wave, four quadrant, fully regenerative SCR rate loop servo amplifiers.

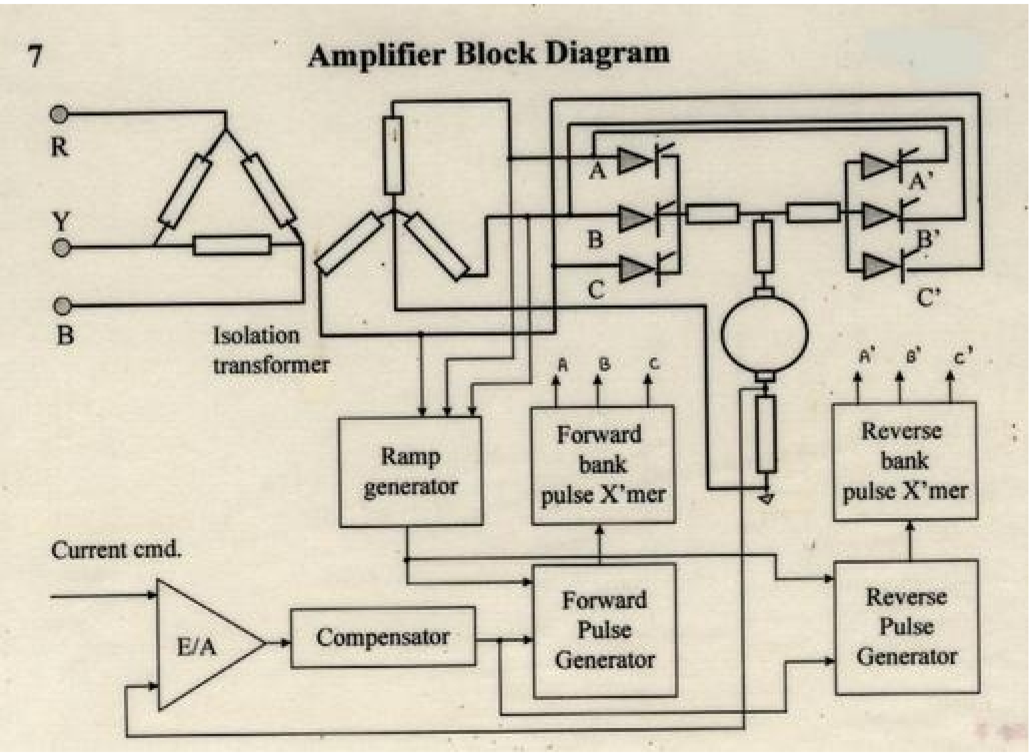


Fig6.3. *Servo amplifier block diagram*

Except for minor component changes on the Motor Control Cards, the basic modules of these amplifiers are interchangeable and the operation of the modules is identical whether used in the TPA/1, TPA/2 or TPA/3 (power supply components will vary depending on secondary voltage from isolation power transformers).

Due the interchangeability of the modules, spare parts cost can be minimized.

Modular construction and the liberal use of test points assure easy field maintenance and troubleshooting.

Other features are :-

- Fail safe dynamic braking
- Programmable torque

- Fusing for system protection or circuit breakers
- Over speed protection
- Motor overload protection
- Not sensitive to line phasing
- Drive up indication
- Motor current monitor output

THEORY OF OPERATION :-

This amplifier is a “Rate Loop” amplifier. A rate loop amplifier is a device that maintains a speed proportional to a command input signal.

The amplifier consists of eight basic modules:

1. Motor Control Card
2. Pulse Generator Card
3. Ramp Generator Card
4. Interlock and Brake Card
5. Power Supply Card
6. Suppression Cards (1, 2 or 3)
7. SCR packs (3, 6 or 9)
8. Mother Board containing items 1-5

The **Motor Control Card** incorporates the necessary circuitry to provide the rate (or velocity) loop function, the current loop function, the motor current monitor and the over-speed protection. The rate loop compares the actual speed as indicated by the tachometer to the commanded speed and generates an error signal to the current loop. The current loop then monitors the actual motor current, compares it with the error signal from the rate loop, and commands more or less current into the motor to cause it to run faster or slower as necessary to satisfy the Rate Loop. Current limiting is also performed by this card, allowing maximum motor performance without encountering commutation problems. The motor current monitor issues a signal for external use which is in direct relation to the actual motor current. This signal will be approximately 8 Volts equal 100 Amps in the motor unless otherwise specified on the system test limit sheet.

The Over-speed circuit monitors the speed of the motor, inhibits the Rate Loop and Current Loop when this speed becomes excessive, and indicates this condition by illuminating the "Over-speed Fault" LED .

The **Pulse Generator Card** accepts the output from the Motor Control Card and produces a pulse train whose position, with respect to line zero crossover, depends on the value of the Motor Control Card output. As the Motor Control Card output increases, the pulse position advances, the current in the motor increases.

The **Ramp Generator Card** produces a reference signal based on line zero crossover allowing the Pulse Generator Card to produce pulse trains to control the SCR firing angles.

The **Interlock and Brake Card** monitors the line voltage and shuts off the firing pulses for all axes upon loss of any line input phase, delays turn on until transients have settled at start up, performs the RGSO "Inhibit" function, and provides a contact opening for external indication that a fault condition exists which has inhibited one or more axes. This card also contains Fail Safe Dynamic Brake, which in the event of the loss of prime power applies pulses to all SCRs, dynamically braking the motor to an emergency stop.

The **Power Supply Card** supplies +/- 15 Volts (regulated) and +24 Volts (unregulated) DC voltage to the amplifier.

The **Suppression Card** contains the circuitry for line transient suppression and SCR protection. This card also contains the SCR pulse transformers, and outputs a signal to the Interlock and Brake Card for use in phase-loss detection

The **SCR packs** are the basic power section of the amplifier. Each pack contains two SCRs: one "forward" and one "reverse". Current is generated into the motor as each SCR is "gated" on by a Pulse Generator Card.

The **Mother Board** serves as a receptacle for all plug-in cards, providing interconnections between cards and holds the input and signal-level output terminal scripts.

AMPLIFIER SUMMARY :-

Amplifier Type	Output	Cont. Current	Peak Current	Bandwidth	Form factor	Relative Cost
Single phase full wave	90 to 160 V	15 to 30 A	90 to 200 A	25 Hz	1.5 to 1.4	0.8
Three phase half wave	160 V	30 to 150 A	200 to 500 A	30 Hz	1.2 to 1.05	1
Six phase half wave	160 V	30 to 150 A	200 to 500 A	50 Hz	1.1 to 1.05	1.2

Fig6.4. *Important amplifier parameters*

7. EQUIPMENT DESCRIPTION

The GMRT servo control system is assembled in three cabinets. The central cabinet house the console, Station Servo Computer, Analog electronics and DC power supplies. The left cabinet is Elevation drive cabinet and the right one is Azimuth drive cabinet. These cabinets house amplifiers, choke, transformers, contactors and other related hardware.

DC REGULATED POWER SUPPLY :-

The DC regulated power supply mounted at the bottom of the control cabinet is powered by 230 V input and generates various DC outputs as given below:-

5 V / 20 A	Station servo computer
+/- 15 V / 5 A	Station servo computer, Analog bin
24 V / 5 A	Relays
110 V / 3 A	Brake supply

The supply is powered on by the key switch. The front panel has pilot lamps, voltage / current meters and switches.

ENCODERS, LIMITS AND CABLE WRAP LOGIC :-

In AZ axis position limit switches are mounted at about +270 and -270 deg positions (i.e. East and West) nearer the bottom end of the AZ shaft. Cables from top pass down through a cable wrap arrangement and cables can take up to -300 deg to +300 deg twist. 17 bit absolute encoder of M/S Teledyne Gurley make is also coupled to the free end of the AZ shaft through flexible coupling. It is adjusted to read 0 deg (approx.) at South (i.e. cable wrap center). Exact read out can be obtained by entering the desired offset angle from HHT. The offset angle must be less than +/- 10 deg. Since the encoder reading wraps around every 360 deg (one rotation) and total allowed AZ movement is 540 deg (-270 to +270), the required extra bit of information is obtained by using a cable wrap limit switch. This limit switch is positioned so as to toggle somewhere between 0 and 45 deg (between South and West). The actuating mechanism is such that it works as an extra memory bit to indicate zone.

AZ angle read out is in the +/- format, allowed movement being within -270 and +270. Thus, as an antenna moves towards West from South (CW movement), the absolute encoder reading increases from 0 deg to 90 deg. Since this region cannot be entered from CCW direction, the actual angle reading is unambiguously derived from encoder reading alone. Similarly, while moving in the CCW direction from South towards East absolute encoder reading decreases from 359 towards 270 (359 is near 0).

It may also be noted that the AZ position limit switches mounted at West and East, have to be used in conjunction with the cable wrap limit switch, to derive the actual limit indication.

Elevation limit switches are positioned so as to get actuated at 15 deg and 110 deg. Encoder is coupled to one end of the EL shaft. Encoder is just adjusted to read 0 deg in horizon and then as the antenna is moved up the angle read out increases.

STOW MOTOR AND LIMIT SWITCHES :-

Antenna can be stowed in the EL axis at 90 deg by inserting motor driven stow pins into slots in the antenna. Limit switches are mounted to indicate to the control system, stow position, stowed and stow released status.

WIND METERS :-

Two wind meters are mounted on the periphery of the dish. The frequency of the pulse train sent by these is measured and is available for display. These readings are also used by the control system, to cause automatic parking operation under high wind conditions. This parking provision is available even under main power loss, by driving the motors from battery.

MOTOR, BRAKE AND TACHO :-

The motors used are 6 HP low inertia DC servo motors with integral fail-safe brake. Brakes are normally applied and released on application of 110 V supply. The tachometer provides DC voltage proportional to the speed of the motor and is used in speed control and over-speed protection. Salient motor ratings are given in the appendix.

AMPLIFIERS AND ANALOG LOOPS :-

Each motor is driven by 4 quadrant regenerative thyristorised DC servo amplifiers of M/S Drive make. Two of these amplifiers are mounted in the respective axis drive cabinet. The amplifiers have regenerative brake provision. They include current controller electronics, current limiting circuits, over-speed trip, over-load indication etc. The drive cabinets also contain transformers, contactors, chokes etc. The analog bin mounted in the central cabinet contains torque-bias, speed loop controller circuits and other analog circuits for both the axes.

CONSOLE :-

The console panel is mounted on the control cabinet. It contains LED based angle read-out displays, auxiliary display, status display matrix, key-switch, mode selection switch, AZON/ELON & AZOFF/ELOFF switches and lamps, slew potentiometers, stow operation switches and indications. The console is used for manual mode of antenna operation.

HAND HELD TERMINAL :-

The ASCII hand held terminal is a detachable unit which has an in-built 2 x 40 LCD alphanumeric display and ASCII keyboard. It is interfaced to the SSC through RS232C serial interface and powered by 5 V power supply. The HHT is used to set and monitor various system parameters. During local mode of operation the antenna can be positioned at any desired angle by entering required commands through the HHT.

BATTERY :-

A DC battery bank is provided at each antenna base. It is used to energize the motors during parking and stowing under power loss conditions.

RELAY INTERLOCKS :-

All the external safety and protection interlocks are based on 24 V DC relays. While designing interlocks for GMRT antenna, the emphasis is on fail safe logic i.e. failure of any component should not lead to malfunction of antenna or cause damage to the system.

STATION SERVO COMPUTER :-

The Station Servo Computer is built around bus structured processor and I/O boards. The bus master is 8086-2 processor running at 8MHz. The field I/O is interfaced to the SSC through back-panel mounted D connectors. It interfaces to the following equipments.

- AZ / EL position encoders and potentiometers
- 2 no of wind meters
- console switches, status indicators and display
- motor brakes and status output
- slow mechanism
- amplifiers
- Hand Held Terminal
- Antenna base computer
- Position Limit Switches

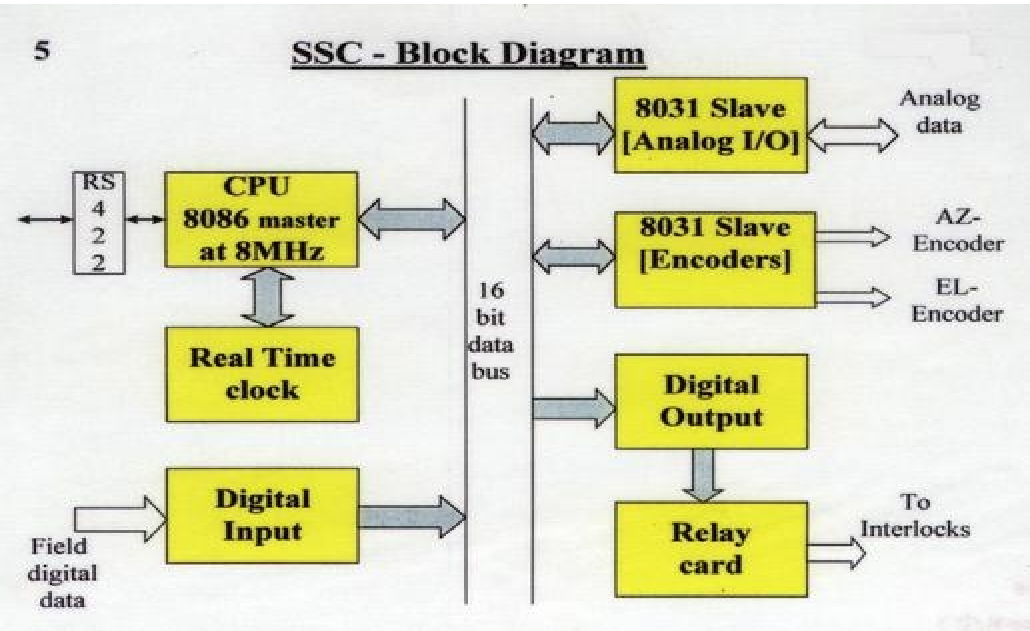


Fig7.1. *Servo Station Computer block diagram*

The SSC performs the following functions:

- Closed loop position control in local and remote modes of operation.
- Handling control and monitor commands from remote ABC
- Generating demand angle trajectory every 100msec based on data received from ABC
- Position measurement and display after off-set correction.
- Scanning contact inputs; performing operational and safety interlocking logic and driving relay outputs.
- Limit release operation
- slow, stow release and parking operation.
- Monitoring currents, speeds, wind speeds etc. and generating trip and interlock condition.
- Handling user commands from HHT for setup, display and control.
- Watch dog trigger
- Time of day
- Power on self test and diagnostics.

8. SERVO SYSTEM OPERATION

A thyristorised DC motor speed controller consists of the following main blocks:-

1. Rate loop
2. Current loop
3. Ramp and pulse generator
4. Interlock and brake
5. Power supply
6. Suppression and SCR packs

RATE LOOP :-

The rate loop compares the actual speed indicated by the tachometer to the commanded speed and generates an error signal to the current loop. The rate loop has differential amplifier at input having gain 1. The output of differential amplifier is applied to error amplifier. The offset of velocity loop can be adjusted to zero by adjusting the POT labeled zero. A JFET is connected across the error amplifier which when turned ON inhibits the rate loop and output of rate loop becomes 0 V. The inhibition of rate loop can be done by CAGE command. With applying +15 V to "CAGE", amplifier is caged (torque limited to zero).

The overspeed circuit monitors the speed of the motor. If this speed becomes excessive, it inhibits the rate loop and current loop and stops the motor by regenerative braking. The condition is indicated by illuminating the overspeed fault LED. The drive up relay opens giving indication that the servo drive is inhibited.

The overspeed detector has latching ability. To come out of overspeed fault, three phase supply is to be put off.

CURRENT LOOP :-

The actual motor current is available as a voltage across .0055%, 100 W shunt resistance. The current loop monitors the actual motor current, compares with the error signal from the rate loop and commands more or less current into the motor to cause it to run faster or slower as necessary to satisfy the rate loop. At higher speed, heavier the motor current, the current ripple increases and commutation becomes poorer. To assure excellent high speed commutation, current limit counter generator is used, which modifies the current command depending on speed. At higher speed of the motor, motor current is limited to lower value and vice-versa. Thus it employs active motor current limiter.

A JFET is connected across the error amplifier which when turned ON inhibits the rate loop and output of rate loop becomes 0 V. The inhibition of rate loop can be done by CAGE command. With applying +15 V to "CAGE", amplifier is caged (torque limited to zero).

The motor current monitor issues a signal for external use which is in direct relation with the actual motor current.

INTERLOCK AND BRAKE :-

This block has got a UJT pulse generator which generate pulses if

1. RGSO link is open
2. loss of any of input line phase

and pulses are applied to all SCR's causing the motor to dissipate its energy in choke+transformer+shunt resistance. Thus dynamically braking the motor to emergency stop.

Interlock perform the RGSO function and provides a contact opening for external indicating that a fault condition exists. The contact opens on following faults:

1. Speed of the motor becoming excessive.
2. Upon loss of any of the line input phase.
3. RGSO link open.

Interlock has a green LED which extinguishes upon loss of any line input phase. On start up it delays the turn on of SCR until transients have settled (GSO + 24 to run).

RAMP AND PULSE GENERATORS :-

A reference signal to the ramp generators are obtained from potential divider put across three phase line. On line zero crossover capacitor starts charging with a constant current. Thus the capacitor voltage serves as reference ramp signal.

The reference ramp is compared with the error signal of the current loop to produce pulse trains to control the SCR firing angles. The pulse position with respect to line zero crossover is in direct proportion with the error signal of the current loop. As the current error increases the pulse position advances, and current in the motor increases.

POWER SUPPLY :-

158 V AC, 50 Hz, single phase is stepped down to 17-0-17 V by a step down transformer which is then rectified and filtered to obtain +/- 24 V unregulated supply. Three terminal adjustable regulators are used to obtain +/- 15 V regulated supply. A green LED turns ON after applying power.

SCR PACKS AND SUPPRESSION :-

The SCR packs are the basic power section of the amplifier. There are two groups of SCRs :- forward group and reverse group. Each consists of three SCRs.

R-C snubbers are connected across each SCR for the suppression of line transients and dv/dt protection of individual SCRs.

Two sets of the three phase half wave circuits connected between a three phase line and a DC motor are used to obtain reversing operation and regenerative braking. One set of three thyristors is used to apply forward +ve current, the other set is used to provide reverse -ve current. Both the sets of thyristors are fired at the same time so that the change over from motoring to regenerating can be done without any time delay. One set works in inverting mode while other in a converting mode.

9. MODE SELECTION

Mode selection is done by mode selector switch provided on the console panel. The sequence for mode selection is MAN, REM, LOC. It is not advisable to change the mode if any of the commands are operational.

The various modes of the servo system are as follows:

1. Standby Mode
2. Remote Mode
3. Local Mode
4. Manual Mode

STANDBY MODE :-

In this mode amplifiers are disabled and brakes are applied to both the axes. Manual Mode switches on the console are disabled and commands from SSC are ignored. SELF TEST by SSC can be carried out in this mode to ascertain proper functioning of relay card and other logic circuitry.

REMOTE MODE :-

In this mode antenna is driven by central control computer through RC 232C interface and the manual and local mode disabled.

LOCAL MODE :-

Here commands to the servo computer are given by Hand Held Terminal (HHT). This mode is primarily meant for initial testing, installation and trouble shooting of the servo system.

MANUAL MODE :-

In this mode all the console switches and slew pots become active while SSC continues to display the status and positions of the antenna. This mode helps in installing and aligning encoders and limit switches. In this mode antenna operates in constant velocity mode, the speed and direction can be selected by

SLEW POTS on console panel. If ELEVATION slew pot points UP (+ve volts) antenna moves up i.e. from 15 deg to 110 deg. If Azimuth slew pot points CCW (+ volts) antenna moves CCW i.e. from +270 deg to -270 deg.

STOP push button is pressed whenever it is required to stop the antenna abruptly. Note that this switch is momentary action hence STOP is activated only as long as it is pressed. The following sequence of operation should be followed to put off the axis in manual mode.

1. Reduce the speed of antenna to zero by SLEW POT.
2. Press STOP push button.
3. Press AZ/EL-OFF push button

PARK :-

A PARK command from console switch, bypasses position loop & starts moving antenna towards zenith with a constant speed of 20 deg/min. Upon reaching zenith, antenna is brought to halt by regenerative braking (by opening RGSO link) & then brakes are applied. The PARK command is automatically initiated in event of emergency condition.

STOW IN :-

Stow command by can come from push-button or SSC. This command is executed only when antenna is at stow position (at zenith) & elevation axis is put off i.e brakes applied & amplifier are off. It turns on stow motors & upon reaching the stow limit switch motors are put off. This command is automatically generated if above conditions are fulfilled & if wind velocity equal to or above 80 kmph.

STOW REL :-

This command can come from push button or SSC. If emergency conditions are prevailing, this command is not executed. When conditions are healthy this command puts on the D.C. Contactor there by applying power to the stow motors. This command resets automatically when stow pins are fully released.

LIMIT SWITCHES (on EL axis) :-

There are six limit switches on elevation. One prelimit and final limit each at 15 deg and 100 deg, two switches near zenith each having one NO and NC contacts.

When antenna reaches 15 deg, it presses PRE limit switch and antenna is brought to halt by regenerative braking and then brakes are applied. Thus antenna is held at EL by brakes.

Here the drive waits for opposite command i.e. input of the amplifiers are continuously monitored and pre limit switch is bypassed if the command is to move in the opposite direction so as to come out of the limit. Brakes are released and amplifiers are energized (by closing RGSO) and antenna starts moving and comes out of limit. Similar action takes place when antenna reaches 110 deg.

One roller switch having one NO and one NC contact is placed at zenith(90 deg). This switch is pressed (ON) by antenna moving up(from 90 to 110 deg). Its closure indicates elevation angle of antenna is more than 90 deg and thus decides the direction of movement(UP/DOWN) of antenna in emergency condition of mains failure.

One roller switch (momentary) having one NO and NC contact is placed along side of above mentioned(90) switch, this switch indicates the stow position and puts off EL axis as soon as it is pressed during PARK command. It is named as “STOW POSITION” switch and comes in action only in case of emergency parking.

EMERGENCY CONDITION :-

1. LOSS OF PHASE 3 phase in mains: Voltages of three phases are sensed separately and loss of phase is detected when line to neutral voltage falls below 200VAC (L-N).
2. Wind velocity reaching 50kmph: Frequency modulated pulses from wind sensors are converted into voltage and then compared with a fixed value to operate a relay.
3. Failure of SSC : A relay contact from SSC which opens in the event of SSC fault indicates emergency condition.

   In the event of (1) to (3) listed above SSC cannot take part in stowing by position loop and stowing takes place without an aid of contactor and gives command to release the brakes(by batteries). Amplifiers are disabled(by opening RGSO). The roller switch at zenith indicates whether antenna is in 15-90 zone or 90-110 zone and hence plays a key role in deciding whether antenna is to be moved up(from 15 deg towards 90 deg) or down(from 110 deg towards 90 deg). This switch at zenith puts on D.C. contactors which applies battery voltage to the motors. As soon as antenna reaches zenith, STOW POSITION switch gets pressed which puts off D.C. contactors and hence disconnect batteries and immediately applies brakes.

LIMIT SWITCHES (on AZ axis) :-

There are six limit switches on AZ axis. Two roller switches each having one NO and NC contacts are placed at +270 deg and -270 deg. PRELIMIT comes before the final limits on both the ends.

Once the PRELIMIT switch at +270 gets operated and opens a contact indicating that antenna is out of limit.

Upon opening of contacts the antenna is brought to halt by opening RGSO and applying axis brakes. Here antenna enters into a standby mode and ignores all rate command in direction same as before. Only command in opposite direction enables axis and brings back antenna out of limit. To achieve this, the inputs to the rate loops are sensed and continuously monitored.

The final limit removes power to the motors by disabling the motor controllers and sets the axis brakes. The final limits can not be electrically over ridden. The relay which is controlling brake ON/OFF and amplifier enable/disable is wired directly through the final limit switches as a redundant safety measure.

10. PCB DESIGN USING SOFTWARE

Now we will focus on the design of printed circuit board for two of the cards previously mentioned: the Motor Control Card and the Interlock & Brake Card, using software. The software we are using for the PCB design is known as "**Altium Designer**".

MOTOR CONTROL CARD: circuit (schematic) diagram :-

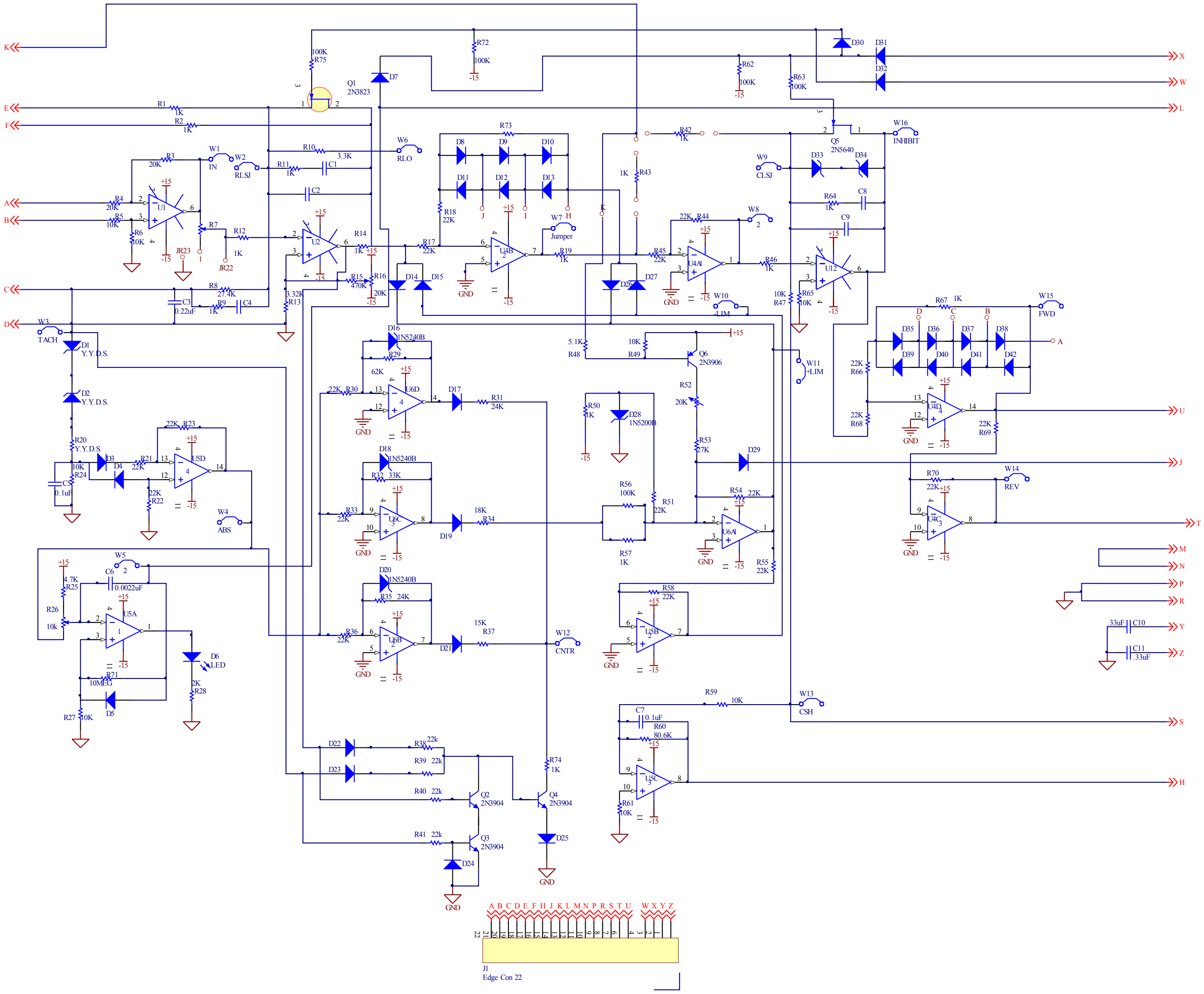


Fig10.1. *Motor Control Card circuit (schematic) diagram*

INTERLOCK AND BRAKE CARD: circuit (schematic) diagram :-

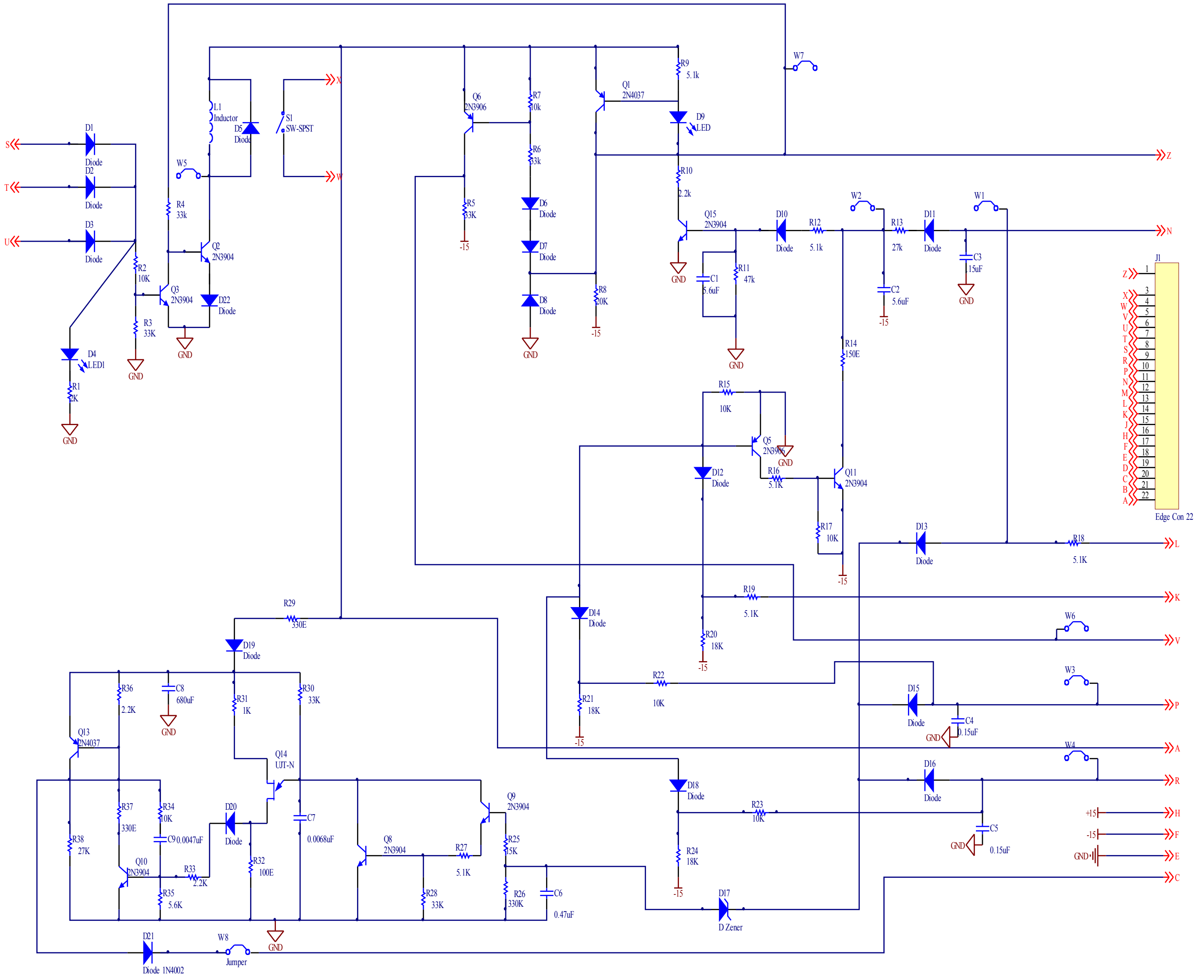


Fig10.2. *Interlock and Brake Card circuit (schematic) diagram*

INTRODUCTION TO ALTIUM DESIGNER :-

The Altium Designer software includes a selection of documents that helps us to understand the Altium Designer environment, find our way around the system, and learn the basics of working in the various editors. It also includes basic tutorials that quickly take us through the process of capturing simple, working projects.

CREATING A NEW SCHEMATIC SHEET :-

We select **File » New » Schematic**, or click on **Schematic Sheet** in the **New** section of the **Files** panel. A blank schematic sheet named Sheet1.SchDoc displays in the design window and the schematic document is automatically added (linked) to the project. The schematic sheet is now listed under **Source Documents** beneath the project name in the **Projects** tab.

We rename the new schematic file (with a .SchDoc extension) by selecting **File » Save As**. We navigate to a location where we would like to store the schematic on your hard disk, then we type the name Motor.SchDoc in the **File Name** field and click on **Save**.

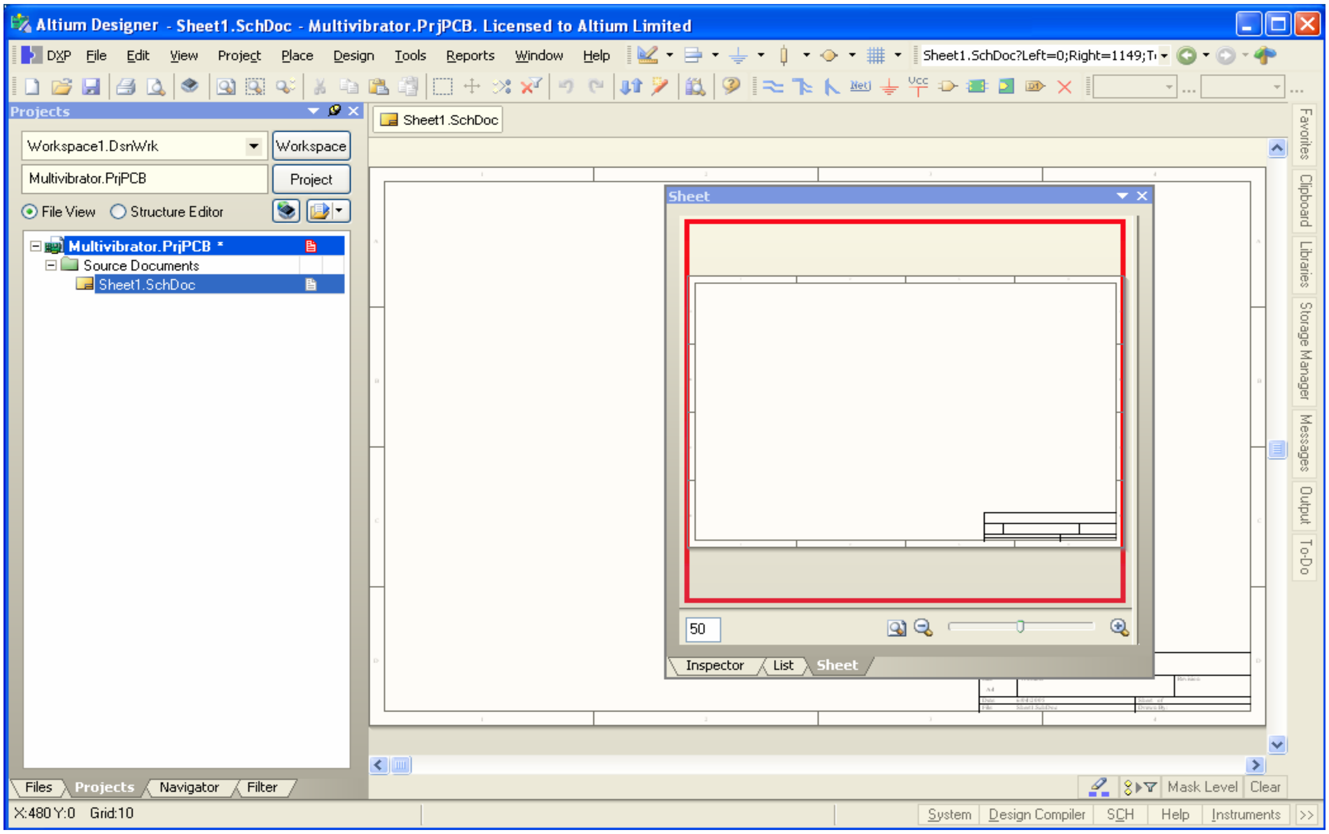


Fig10.3. *Creating a new schematic sheet*

When the blank schematic sheet opens we notice that the workspace changes. The main toolbar includes a range of new buttons, new tool bars are visible, the menu bar includes new items and the **Sheet** panel is displayed. We are now in the Schematic Editor.

ADDING SCHEMATIC SHEETS TO A PROJECT :-

If the schematic sheets we want to add to a project file have been opened as Free Documents, we right-click on the project name in the Projects panel and select **Add Existing to Project**. We choose the free documents name(s) and click **Open**. Alternatively, we can drag-and-drop the free document into the project documents list in the Projects panel. The schematic sheet is now listed under Source Documents beneath the project name in the Projects tab and is linked to the project file.

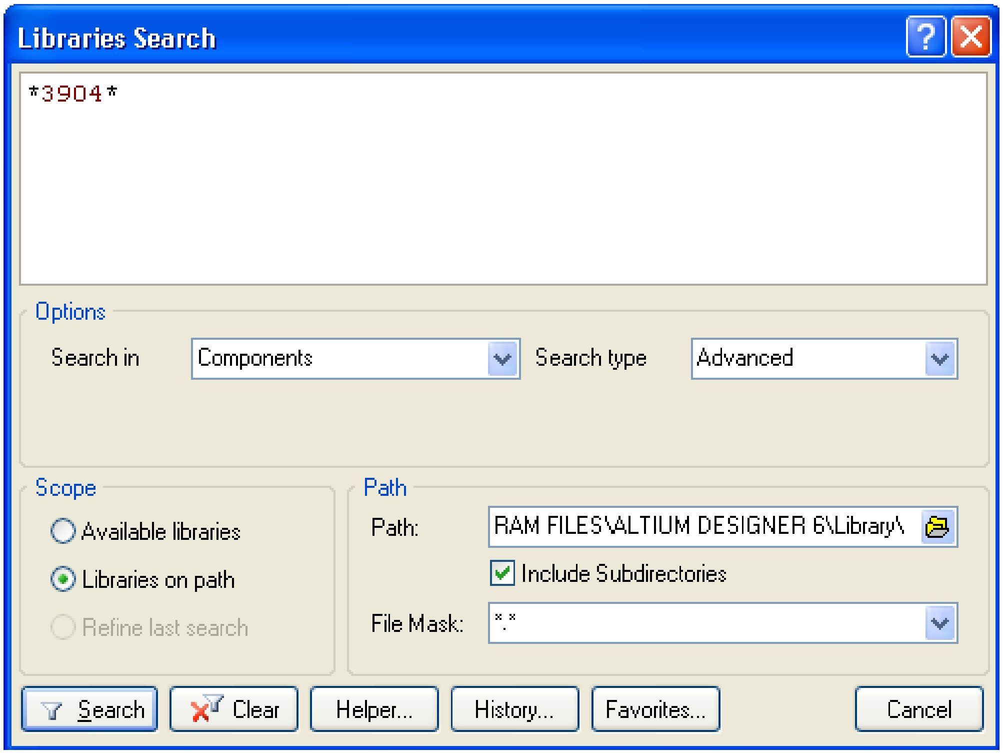
LOCATING THE COMPONENTS AND LOADING THE LIBRARIES :-

To manage the thousands of schematic symbols included with Altium Designer, the Schematic Editor provides powerful library search features. Although the components we require are in the default installed libraries, it is useful to know how to search through the libraries to find components.

1. We click on the **Libraries** tab to display the **Libraries** panel.

2. We press the **Search** button in the **Libraries** panel, or select **Tools** » **Find Component**, to open the *Libraries Search* dialog.

3. We ensure that **Search in** drop down in the **Options** region is set to **Components** for this example. There are other options for library searching using different criteria.



Libraries Search

```
*3904*
```

Options

Search in: Components

Search type: Advanced

Scope

○ Available libraries

● Libraries on path

○ Refine last search

Path

Path: RAM FILES\ALTIUM DESIGNER 6\Library\

☑ Include Subdirectories

File Mask: *.*

Fig10.4. *Libraries search*

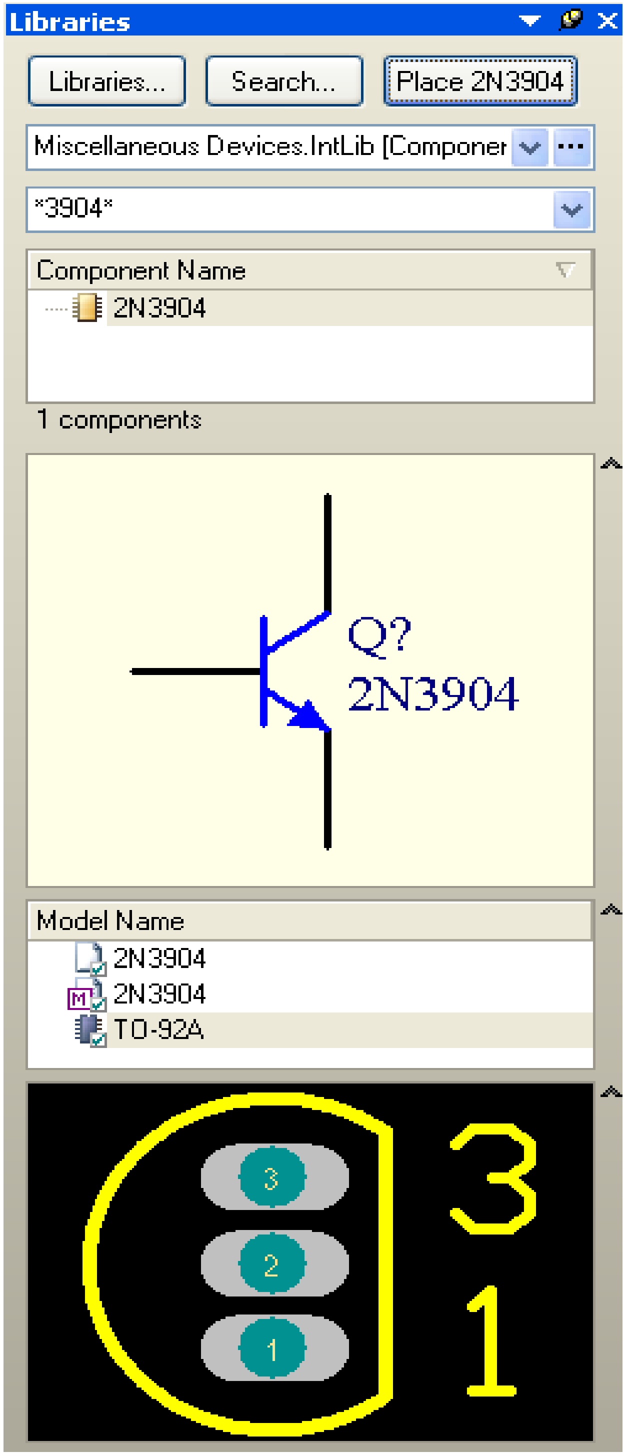
4. We ensure that the **Scope** is set to **Libraries on Path** and that the **Path** field contains the correct path to our libraries. If we accepted the default directories during installation, the path should be C:\Program Files\Altium Designer 6\Library\. We click on the folder icon to browse to the library folder. Ensure that

the **Include Sub directories** box is not selected (not ticked) for this example

We want to search for all references to 3904, so type *3904* in the query section at the top of the *Libraries Search* dialog. The * symbol is a wild card used to take into account the different prefixes and suffixes used by different manufacturers.

6. We click the **Search** button to begin the search. The Query Results are displayed in the **Libraries** panel as the search takes place.

7. We click on the component name 2N3904 found in the Miscellaneous Devices.IntLib library to select it. This library has symbols for all the available simulation-ready BJT transistors.



Miscellaneous Devices.IntLib [Componer

3904

Component Name

2N3904

1 components

Model Name

2N3904

2N3904

TO-92A

Fig10.5. *Searching for components*

8. 8. If we choose a component that resided in a library that was not currently installed, we would be

asked to confirm the installation of that library before we could place the component on our schematic. Since the Miscellaneous Devices library we need is already installed by default, the component is ready to place.

The added libraries will appear in the drop down list at the top of the Libraries panel. As we click on a library name in the upper list, the component library are listed below. The component filter in the panel can then be used to quickly locate a component within a library.

PLACING THE COMPONENTS ON OUR SCHEMATIC :-

1. We select **View » Fit Document** [shortcut: **V**, **D**] to ensure our schematic sheet takes up the full window.

2. We make sure the **Libraries** panel is displayed by clicking on the **Libraries** tab.

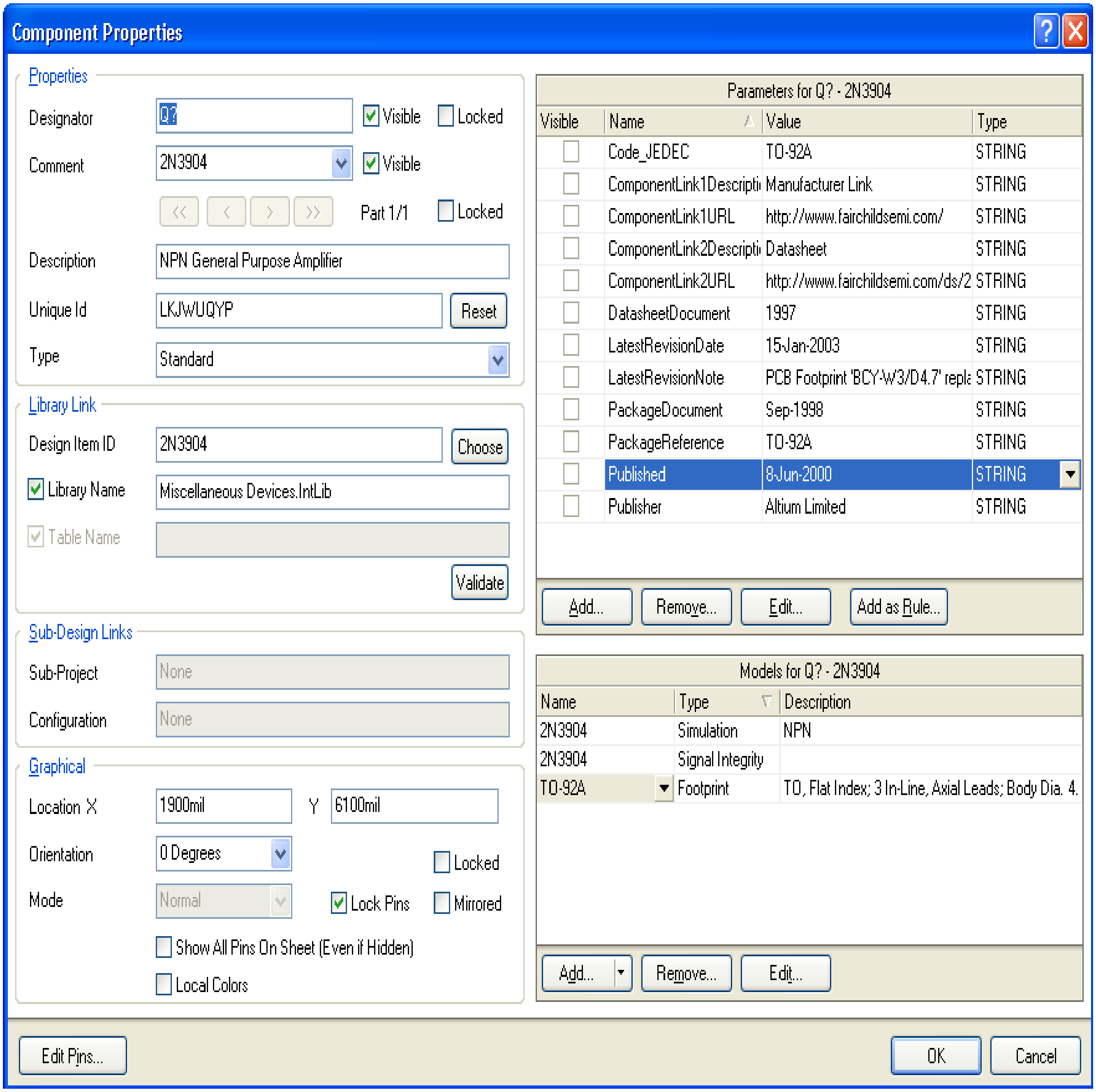
3. Q1 and Q2 are BJT transistors, so we select the Miscellaneous Devices.IntLib library from the Libraries drop-down list at the top of the Libraries panel to make it the active library.

4. We use the filter to quickly locate the component we need. The default wild-card (*) will list all components found in the library. We set the filter by typing *3904* in the filter field below the Library name. A list of components which have the text "3904" as part of their Component Name field will be displayed.

5.In the **Properties** section of the dialog, we set the value for the first component designator by typing Q1 in the **Designator** field.

6. Next we will check the footprint that will be used to represent the component in the PCB.

The link between the schematic component and the PCB component is the footprint. The footprint specified in the schematic is loaded from the PCB library when we load the netlist. We double-click on a schematic component to specify the footprint.



Component Properties

Properties

Designator Q? ☑ Visible ☐ Locked

Comment 2N3904 ☑ Visible

Part 1/1 ☐ Locked

Description NPN General Purpose Amplifier

Unique Id LKJWUQYP

Type Standard

Library Link

Design Item ID 2N3904

☑ Library Name Miscellaneous Devices.IntLib

☑ Table Name

Sub-Design Links

Sub-Project None

Configuration None

Graphical

Location X 1900mil Y 6100mil

Orientation 0 Degrees ☐ Locked

Mode Normal ☑ Lock Pins ☐ Mirrored

☐ Show All Pins On Sheet (Even if Hidden)

☐ Local Colors

Parameters for Q? - 2N3904

Visible	Name	Value	Type
☐	Code_JEDEC	TO-92A	STRING
☐	ComponentLink1Descripti	Manufacturer Link	STRING
☐	ComponentLink1URL	http://www.fairchildsemi.com/	STRING
☐	ComponentLink2Descripti	Datasheet	STRING
☐	ComponentLink2URL	http://www.fairchildsemi.com/ds/2	STRING
☐	DatasheetDocument	1997	STRING
☐	LatestRevisionDate	15-Jan-2003	STRING
☐	LatestRevisionNote	PCB Footprint 'BCY-W3/D4.7' repla	STRING
☐	PackageDocument	Sep-1998	STRING
☐	PackageReference	TO-92A	STRING
☐	Published	8-Jun-2000	STRING
☐	Publisher	Altium Limited	STRING

Models for Q? - 2N3904

Name	Type	Description
2N3904	Simulation	NPN
2N3904	Signal Integrity	
TO-92A	Footprint	TO, Flat Index; 3 In-Line, Axial Leads; Body Dia. 4.

Fig10.6. *Editing the component properties*

We are now ready to place the part.

1. We move the cursor (with the transistor symbol attached) to position the transistor as required on the sheet. Once we are happy with the transistor's position, we left-click or press **ENTER** to place the

transistor onto the schematic.

2. We move the cursor and we will find that a copy of the transistor has been placed on the schematic sheet, but we are still in part placement mode with the part outline floating on the cursor. This feature of Altium Designer allows us to place multiple parts of the same type. So now we place the second transistor. This transistor is the same as the previous one, so there is no need to edit its attributes before we place it. Altium Designer will automatically increment a component's designator when we place a series of parts. In this case, the next transistor we place will automatically be designated Q2.

When we are in any editing or placement mode (a cross hair cursor is active), moving the cursor to the edge of the document window will automatically plan the document.

If we accidentally plan too far while we are wiring up our circuit, press V, F (View » Fit All Objects) to redraw the schematic window, showing all placed objects. This can be done even when we are in the middle of placing an object.

We use the following keys to manipulate the part floating on the cursor:

- Y flips the part vertically
- X flips the part horizontally
- Space bar rotates the part by 90° anti-clockwise.

Since we have now placed all the transistors, we will exit part placement mode by clicking the right mouse button or pressing ESC key. The cursor will revert back to a standard arrow.

To edit the attributes of an object placed on the schematic, we double-click the object to open its *Component Properties* dialog.

<u>WIRING UP THE CIRCUIT</u> :-

- Wiring is the process of creating connectivity between the various components of our circuit.
- To graphically edit the shape of a wire, or any other graphical object once it has been placed, we position the arrow cursor over it and click once.

- Whenever a wire runs across the connection point of a component, or is terminated on another wire, Altium Designer will automatically create a junction.
- When placing wires, we have to keep in mind the following points:

  - We left-click or press ENTER to anchor the wire at the cursor position;

  - We press BACKSPACE to remove the last anchor point;

  - After placing the last segment of a wire, we right-click or press ESC to end the wire placement. The cursor will remain as a cross hair and we can begin placing another wire.
- We right-click again or press ESC to exit wire placement mode.

Altium Designer has a multilevel Undo, allowing us to undo any number of previous actions. The maximum number of Undo steps is user-configurable and limited only by the available memory on our computer.

CHECKING THE ELECTRICAL PROPERTIES OF OUR SCHEMATIC :-

Schematic diagrams in Altium Designer are more than just simple drawings – they contain electrical connectivity information about the circuit. We can use this connectivity awareness to verify our design. When we compile a project, Altium Designer checks for errors according to the rules set up in the **Error Reporting** and **Connection Matrix** tabs and any violations generated will display in the message panel.

COMPILING THE PROJECT :-

Compiling a project checks for drafting and electrical rules errors in the design documents and puts us into a debugging environment. We have already set up the rules in the **Error Checking** and **Connection Matrix** tabs of the *Options for Project* dialog.

1. To compile a project, select **Project » Compile PCB Project**.

2. When the project is compiled, any errors generated will display in the **Messages** panel. Click on this

panel to check for errors (**View » Workspace Panels » System » Messages**). The compiled documents will be listed in the **Navigator** panel, together with a flattened hierarchy, components and nets listed and a connection model that can be browsed.

If our circuit is drawn correctly, the **Messages** panel should not contain any errors. If the report gives errors, check our circuit and ensure all wiring and connections are correct.

The **Messages** panel will display warning messages indicating we have unconnected pins in our circuit. Select **View » Workspace Panels » System » Messages** if the **Messages** panel is not displayed.

3. We double-click on an error or warning in the **Messages** panel and the *Compile Errors* window will display with details of the violation. From this window, we can click on an error and jump to the violating object in a schematic to check or correct the error.

CREATING A NEW PCB DOCUMENT :-

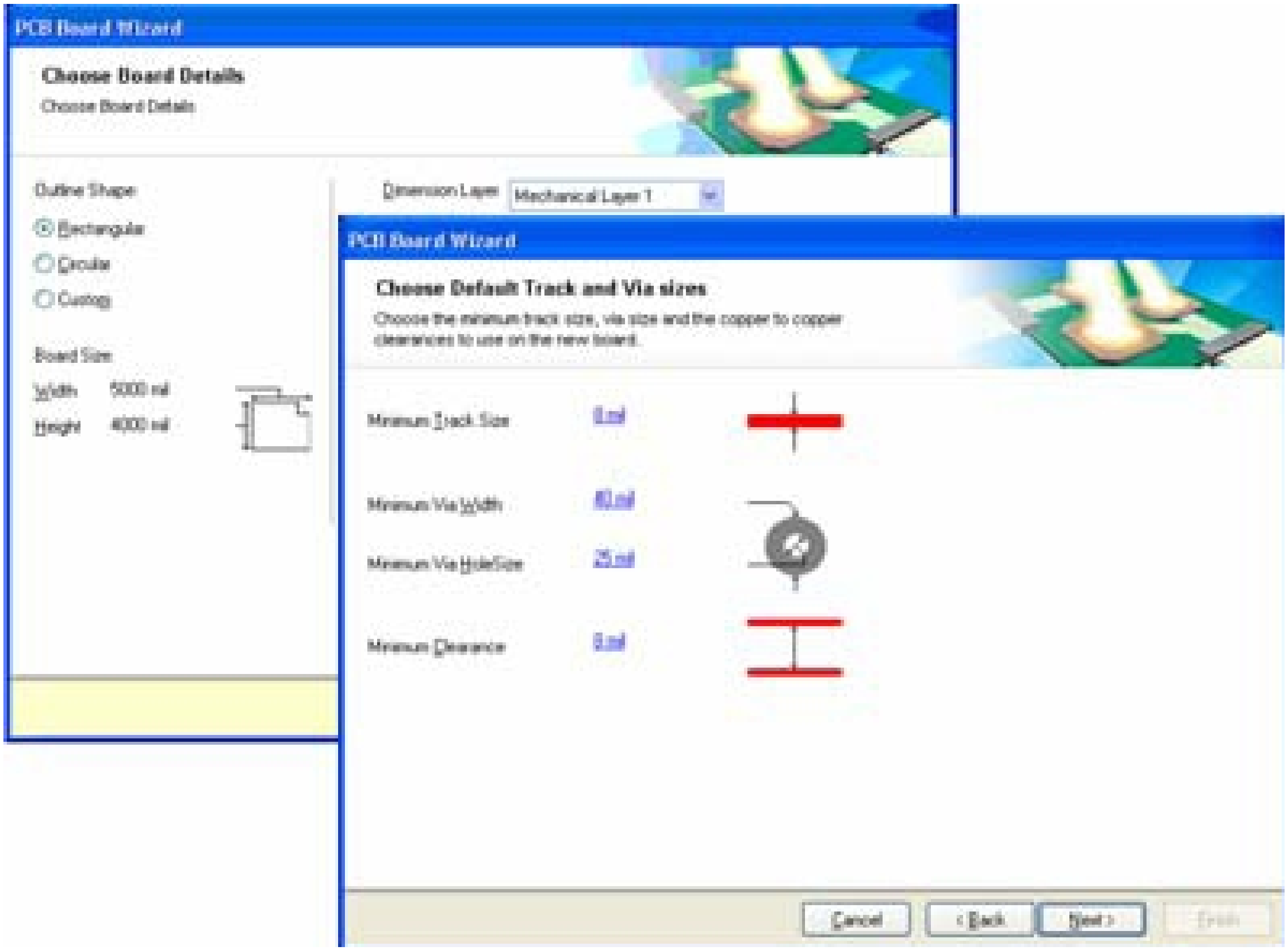
Before we transfer the design from the **Schematic Editor** to the **PCB Editor, we** need to create the blank PCB with at least a board outline. The easiest way to create a new PCB design in Altium Designer is to use the **PCB Board Wizard**, which allows us to choose from industry-standard board outlines as well as create our own custom board sizes. At any stage we can use the **Back** button to check or modify previous pages in the wizard.

To create a new PCB using the PCB Wizard, we complete the following steps:

1. We create a new PCB by clicking on **PCB Board Wizard** in the **New from Template** section at the bottom of the **Files** panel. If this option is not displayed on the screen, we close some of the sections above by clicking on the up arrow icons.

2. The **PCB Board Wizard** opens. The first screen we see is the introduction page. We click the **Next** button to continue.

3. We set the measure units to Metric as we use millimeter.



Choose Board Details

Choose Board Details

Outline Shape

◉ Rectangular

○ Circular

○ Custom

Board Size

Width 5000 mil

Height 4000 mil

Dimension Layer: Mechanical Layer 1

Choose Default Track and Via sizes

Choose the minimum track size, via size and the copper to copper clearances to use on the new board.

Minimum Track Size 8 mil

Minimum Via Width 40 mil

Minimum Via HoleSize 25 mil

Minimum Clearance 8 mil

Fig10.7. *Creating a new PCB document*

4. The third page of the wizard allows us to select the board outline we wish to use. We will enter our own board size. We select **Custom** from the list of board outlines and click **Next**.

5. In the next page we enter custom board options. For our circuit, a board of dimensions 132mm x 108 mm is customized. Select **Rectangular** type 132mm in **Width** and 108mm **Height** fields. We deselect **Title Block & Scale**, **Legend String** and **Dimension Lines**. We click **Next** to continue.

6. This page allows us to select the number of layers in the board. We will need two signal layers and no power planes. We click **Next** to continue.

7. We choose the via styles used in the design by selecting Thru hole **Vias only** and click **Next**.

8. The next page allows us to set the component/track technology (routing) options. We select the **Through-hole components** option and set the number of tracks between adjacent pads to **One Track**. Click **Next**.

9. The next page allows us to set up some of the design rules for track width and via sizes that apply to our board. We leave the options on this screen set to their defaults. We click **Next**.

10. We click **Finish**. The **PCB Board Wizard** has now collected all the information it needs to create your new board. The PCB Editor will now display a new PCB file named PCB1.PcbDoc.

11. The PCB document displays with a default sized white sheet and a blank board shape (black area with grid). To turn it off, we select **Design » Board Options** and deselect **Display Sheet** in the *Board Options* dialog.

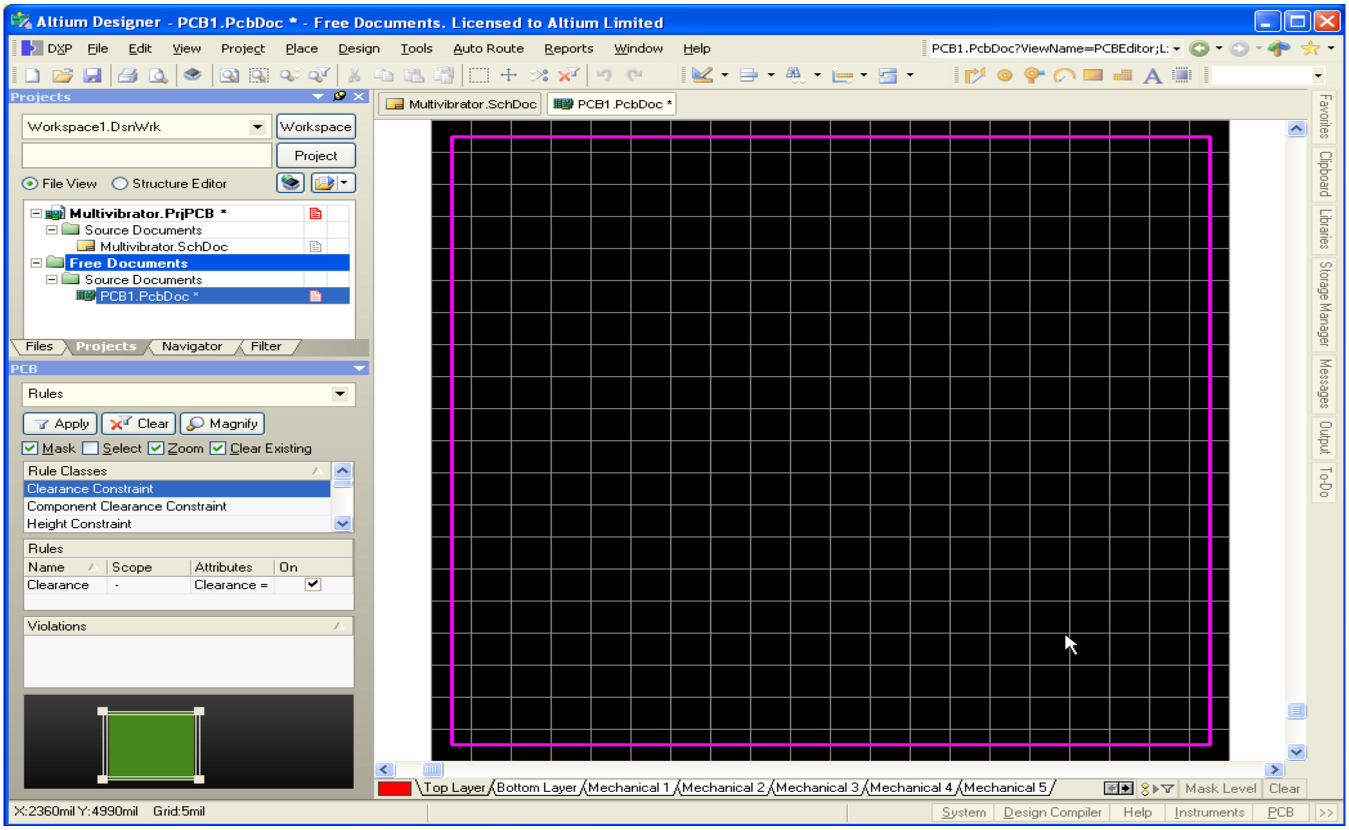


Fig10.8. *PCB board before placing the components*

ADDING A NEW PCB TO A PROJECT :-

If the PCB we want to add to a project file has been opened as a Free Document, we right-click on the PCB project file in the **Projects** panel and select **Add Existing to Project**. We choose the new PCB file name and click on **Open**. The PCB is now listed under **Source Documents** beneath the project in the **Projects** panel and is linked to the project file. We can also do this by dragging the free document and dropping it on to project file. We save the project file.

TRANSFERRING THE DESIGN :-

Before transferring the schematic information to the new blank PCB, we make sure all the related libraries for both schematic and PCB are available. Since only the default installed integrated libraries are used in this tutorial, the footprints will already be included. Once the project has been compiled and any errors in the schematic fixed, we use the **Update PCB** command to generate ECOs that will transfer the schematic information to the target PCB.

Updating the PCB :-

To send the schematic information to the target PCB in our project:

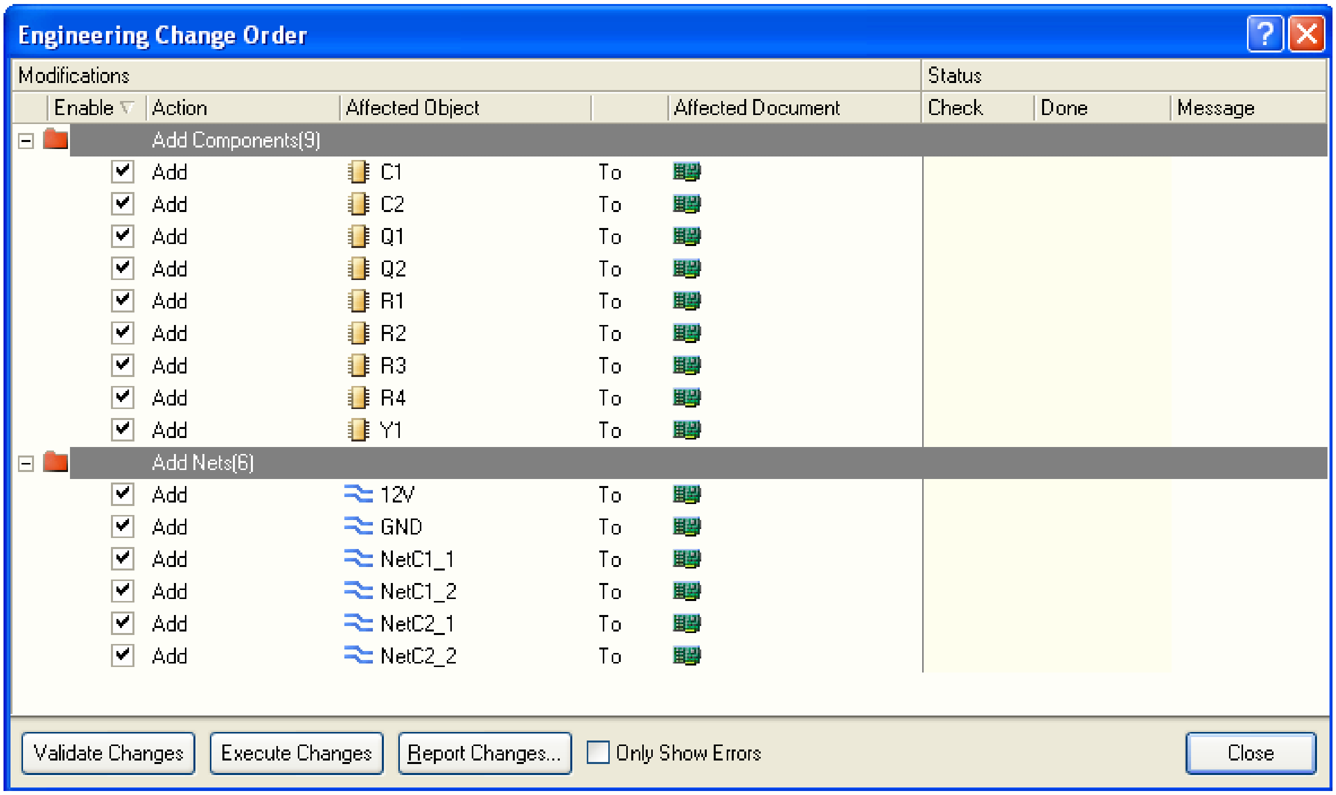
1. We open the schematic document.

2. We select **Design » Update PCB Document** . The project compiles and the *Engineering Change Order* dialog displays.

3. We click on **Validate Changes**. If all changes are validated, the green ticks appear in the Status list. If the changes are not validated, close the dialog, we check the **Messages** panel and clear any errors.

4. We click on **Execute Changes** to send the changes to the PCB. When completed, the **Done** column entries become ticked.

5. We click **Close** and the target PCB opens with components positioned ready for placing on the board. We use the shortcut **V**, **D** (**View » Document**) if we cannot see the components in our current view.



Modifications					Status		
Enable	Action	Affected Object		Affected Document	Check	Done	Message
Add Components(9)							
☑	Add	C1	To				
☑	Add	C2	To				
☑	Add	Q1	To				
☑	Add	Q2	To				
☑	Add	R1	To				
☑	Add	R2	To				
☑	Add	R3	To				
☑	Add	R4	To				
☑	Add	Y1	To				
Add Nets(6)							
☑	Add	12V	To				
☑	Add	GND	To				
☑	Add	NetC1_1	To				
☑	Add	NetC1_2	To				
☑	Add	NetC2_1	To				
☑	Add	NetC2_2	To				

Fig10.9. *Change order*

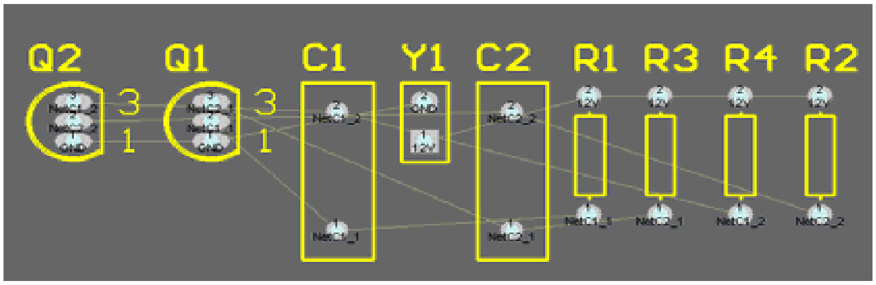


Fig10.10. *Components before being placed on the board*

<u>SETTING UP THE PCB WORKSPACE</u> :-

Before we start positioning the components on the board, we need to set up the PCB workspace, such as the grids, layers and design rules. The PCB Editor workspace is capable of rendering the PCB design in both 2D and 3D modes.

2D mode is a multi-layered environment that is ideal for normal PCB design routines such as placing components, routing and connecting. 3D mode is useful for examining our design both inside and out as a full 3D model (3D mode does not provide the full range of functionality available in 2D mode). We can switch between 2D and 3D modes through **File » Switch To 3D** or **File » Switch To 2D.**

POSITIONING THE COMPONENTS ON THE PCB :-

Now we can start to place the components in their right positions.

1. We press the **V**, **D** shortcut keys to zoom in on the board and components.

2. To place connector Y1, we position the cursor over the middle of the outline of the connector, and click and-hold the left mouse button. The cursor will change to a cross hair and jump to the reference point for the part. While continuing to hold down the mouse button, we move the mouse to drag the component.

3. We position the footprint towards the left-hand side of the board (ensuring that the whole of the component stays within the board boundary).

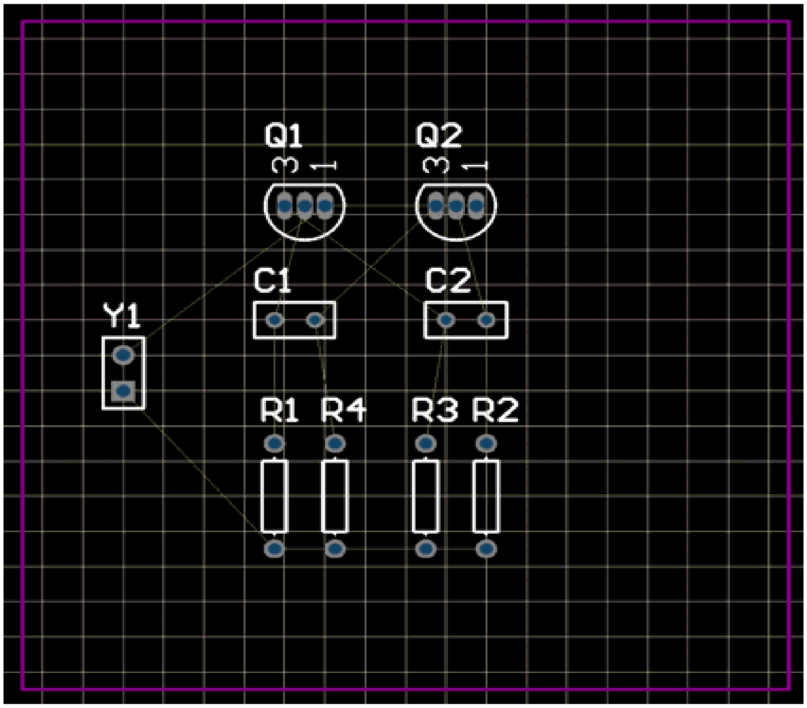


Fig10.11. *Components placed on the board*

4. When the component is in position, release the mouse button to drop it into place. We note how the connection lines drag with the component.

5. We reposition the remaining components. We use the **SPACEBAR** key as necessary to rotate (increments of 90º anti-clockwise) components as we drag them. We re-optimize the connection lines as we position each component.

Component text can be repositioned in a similar fashion – we click-and-hold to drag the text and press the **SPACEBAR** to rotate it.

The connection lines are automatically re-optimized as we move a component. In this way we can use the connection lines as a guide to the optimum position and orientation of the component as we place it.

LAYER MANAGER:-

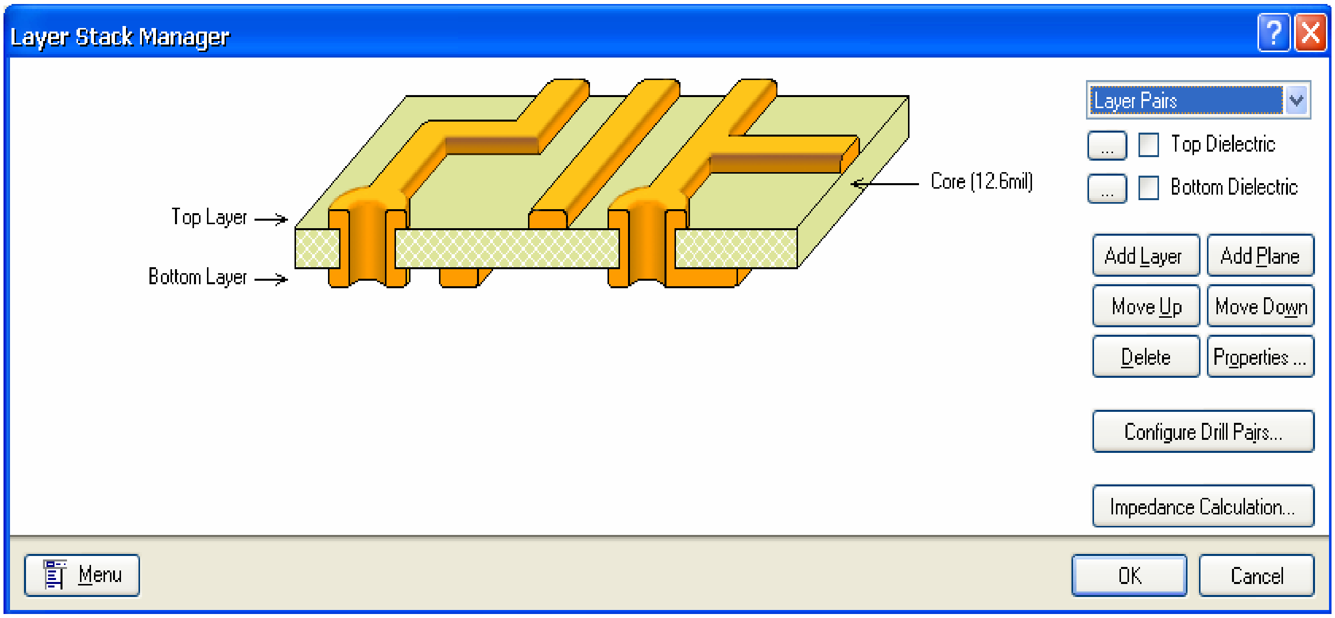


Fig10.12. *Layer stack manager*

MANUALLY ROUTING THE BOARD :-

Routing is the process of laying tracks and vias on the board to connect the components. Altium Designer makes this job easy by providing a number of sophisticated manual routing tools as well as the powerful topological auto-router, which optimally routes the whole or part of a board at the touch of a button.

While auto-routing provides an easy and powerful way to route a board, there will be situations where you will need exact control over the placement of tracks. In these situations we can manually route part or all of our board. In this section of the tutorial, we will manually route the entire board "single-sided", with all tracks on the bottom layer

We will now place tracks on the bottom layer of the board, using the "ratsnest" connection lines to guide us. Tracks on a PCB are made from a series of straight segments. Each time there is a change of direction, a new track segment begins. Also, by default Altium Designer constrains tracks to a vertical, horizontal or 45° orientation, allowing us to easily produce professional results. This behavior can be customized to suit our needs.

1. We enable and show the Bottom Layer by pressing the shortcut key **L** to display the View Configurations dialog. We click on the **Show check-box** next to Bottom Layer in the Signal Layers section. We click **OK** and the Bottom Layer tab is displayed in the design window.

2. We select **Place » Interactive Routing** from the menus [shortcut: **P**, **T**] or click the **Interactive Routing** button. The cursor will change to a cross hair indicating we are in track placement mode.

3. We examine the layer tabs that run along the bottom of the document workspace. The **Top Layer** tab should currently be active. To switch to the bottom layer without dropping out of track placement mode, press the ***** key on the numeric keypad. This key toggles between the available signal layers. The **Bottom Layer** tab should now be active.

4. The position the cursor over the bottom-most pad on connector Y1. We left-click or press **ENTER** to anchor the first point of the track.

5. We move the cursor towards the bottom pad of the resistor R1. We note how the track is laid. By default, tracks are constrained to vertical, horizontal or 45° directions. We also note that the track has two segments. The first (coming from the starting pad) is solid blue. This is the track segment we are actually placing. The second segment (attached to the cursor) is called the "look-ahead" segment and is drawn in outline. This segment allows us to look ahead at where the next track segment we lay could be positioned so that you can easily work our way around obstacles, maintaining a 45°/90° track orientation.

6. We position the cursor over the middle of the bottom pad of resistor R1 and left-click, or press the

ENTER key. We note that the first track segment turns blue, indicating that it has been placed on the Bottom Layer. We move the cursor around a little and we see that we still have two segments attached to the cursor: a solid blue segment that will be placed with the next mouse click and an outlined "look-ahead" segment to help us position the track.

7. We re-position the cursor over the bottom pad of R1. We will have a solid blue segment extending from the previous segment to the pad. We left-click to place the solid blue segment.

We have just routed the first connection.

8. We move the cursor to position it over the bottom pad of resistor R4. We note: A solid blue segment extends to R4. We left-click to place this segment.
9. We now move the cursor to the bottom pad of resistor R3. We note that this segment is not solid blue, but drawn in outline indicating it is a look-ahead segment. This is because each time we place a track segment the mode toggles between starting in a horizontal/vertical direction and starting at 45°. Currently it is in the 45° mode. We press the **SPACEBAR** key to toggle the segment start mode to horizontal/vertical. The segment will now be drawn in solid blue. We left-click or press the **ENTER** key to place the segment.
10. We move the cursor to the bottom of resistor R2. Once again we will need to press the **SPACEBAR** key to toggle the segment start mode. We left-click or press the **ENTER** key to place the segment.
11. We have now finished routing the first net. We right-click or press the **ESC** key to indicate that we have finished placing this track. The cursor will remain a cross hair, indicating that we are still in track placement mode, ready to place the next track. We press the **END** key to redraw the screen so that we can clearly see the routed net.
12. We can now route the rest of the board in a similar manner to that described in the previous steps. Figure shows the manually routed board.

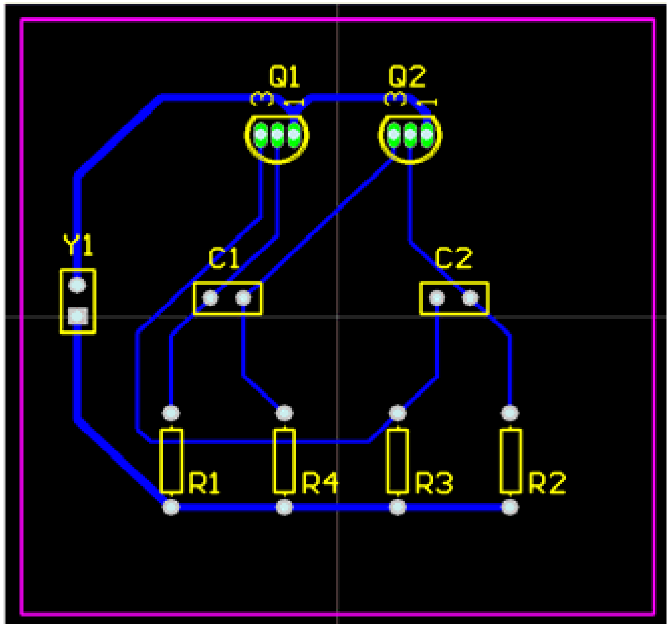


Fig10.13. *A manually routed board*

Tips for Placing Tracks :-

We keep in mind the following points as we are placing the tracks:

• Left-clicking the mouse (or pressing the **ENTER** key) places the track segment drawn in solid color. The outlined segment represents the look-ahead portion of the track. Placed track segments are shown in the layer color.

• We press the **SHIFT** + **SPACEBAR** key to cycle through the various track corner modes. The styles are: any angle, 45°, 45° with arc, 90° and 90° with arc. We press **SPACEBAR** to toggle the corner direction for all but any angle mode.

• We press the **END** key at any time to redraw the screen.

• We press the **V**, **F** shortcut keys at any time to redraw the screen to fit all objects.

• We press the **PAGE UP** and **PAGE DOWN** keys at any time to zoom in or out, centered on the cursor position. Use the mouse wheel to pan left and right. We hold the **CTRL** key down to zoom in and out with the mouse-wheel.

- We press the **BACKSPACE** key to “unplace” the last track segment.
- We right-click or press **ESC** when we have finished placing a track and want to start a new one.
- We cannot accidentally connect pads that should not be wired together. Altium Designer continually monitors board connectivity and prevents us from making connection mistakes or crossing tracks.
- To delete a track segment, we left-click on it to select it. The segment’s editing handles will appear (the rest of the track will be highlighted). We press the **DELETE** key to clear the selected track segment.
- Re-routing is easy – we simply route the new track segments, when we right-click to finish the old redundant track segments will automatically be removed.
- When we have finished placing all the tracks on your PCB, we right-click or press the **ESC** key to exit placement mode. The cursor will change back to an arrow.

AUTOMATICALLY ROUTING THE BOARD :-

We select **Auto Route » All**. The *Situs Routing Strategies* dialog displays. We click on **Route All**. The Messages panel displays the process of the auto routing.

It is to be noted that the tracks placed by the auto router appear in two colors: red indicates that the track is on the top signal layer of the board and blue indicates the bottom signal layer. The layers that are used by the auto router are specified in the **Routing Layers** design rule, which was set up by the **PCB Board Wizard**. We will also notice that the two power net tracks running from the connector are wider, as specified by the two new Width design rules we set up.

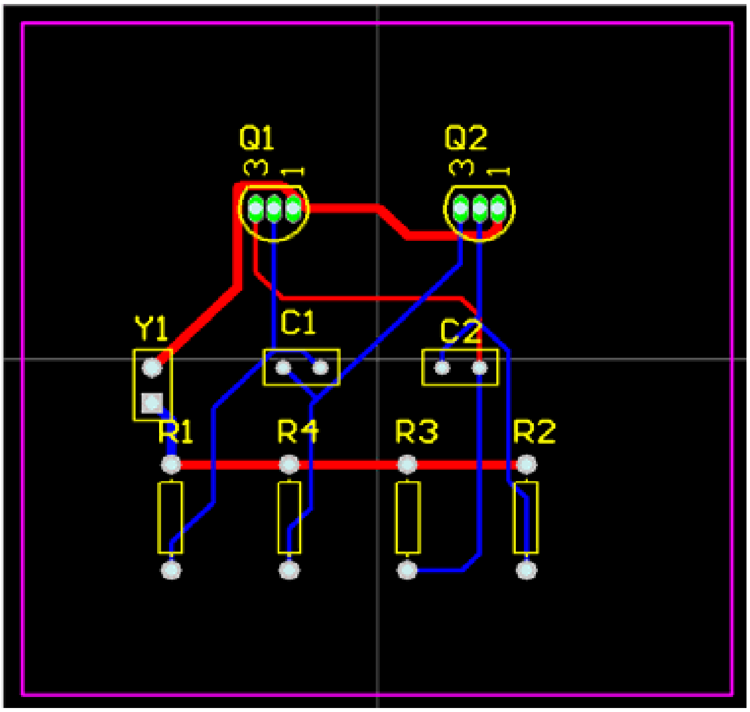


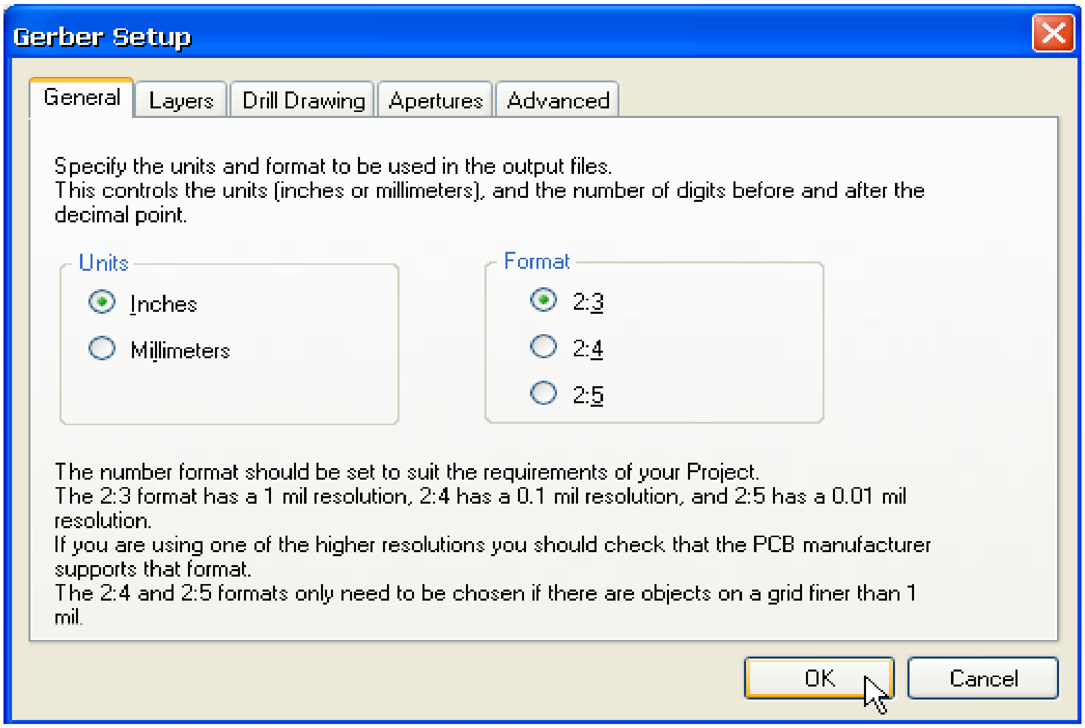
Fig10.14. *An automatically routed board*

GENERATING GERBER FILES :-

Each Gerber file corresponds to one layer in the physical board – the component overlay, top signal layer, bottom signal layer, the solder masking layers and so on. It is advisable to consult with our PCB manufacturer to confirm their requirements before generating the Gerber and NC drill files required to fabricate our design.

To create the manufacturing files for the PCB:

1. We make the PCB the active document, then select **File » Fabrication Outputs » Gerber Files**. The *Gerber Setup* dialog displays.



Specify the units and format to be used in the output files.
This controls the units (inches or millimeters), and the number of digits before and after the decimal point.

Units
● Inches
○ Millimeters

Format
● 2:3
○ 2:4
○ 2:5

The number format should be set to suit the requirements of your Project.
The 2:3 format has a 1 mil resolution, 2:4 has a 0.1 mil resolution, and 2:5 has a 0.01 mil resolution.
If you are using one of the higher resolutions you should check that the PCB manufacturer supports that format.
The 2:4 and 2:5 formats only need to be chosen if there are objects on a grid finer than 1 mil.

Fig10.15. *Gerber setup*

2. We click on the **Layers** tab to select which layers to use. We click on **Plot Layers** and select **Used On**. We click **OK** to accept the other default settings.

3. The Gerber files are produced and the CAM Editor (CAMtastic) opens to display the files. The Gerber files are stored in the Project Outputs folder which is automatically created in the folder where your project files reside. Each file has the file extension added that corresponds to the layer name, eg. Motor.GTO for Gerber Top Overlay. These are added to the **Projects** panel under Generated CAMtastic Documents.

If we do not want output files to automatically open when they are created, we select Project » Project Options, then we click on the Options tab and deselect Open Outputs after compile**.**

PCB LAYOUT FOR MOTOR CONTROL CARD :-

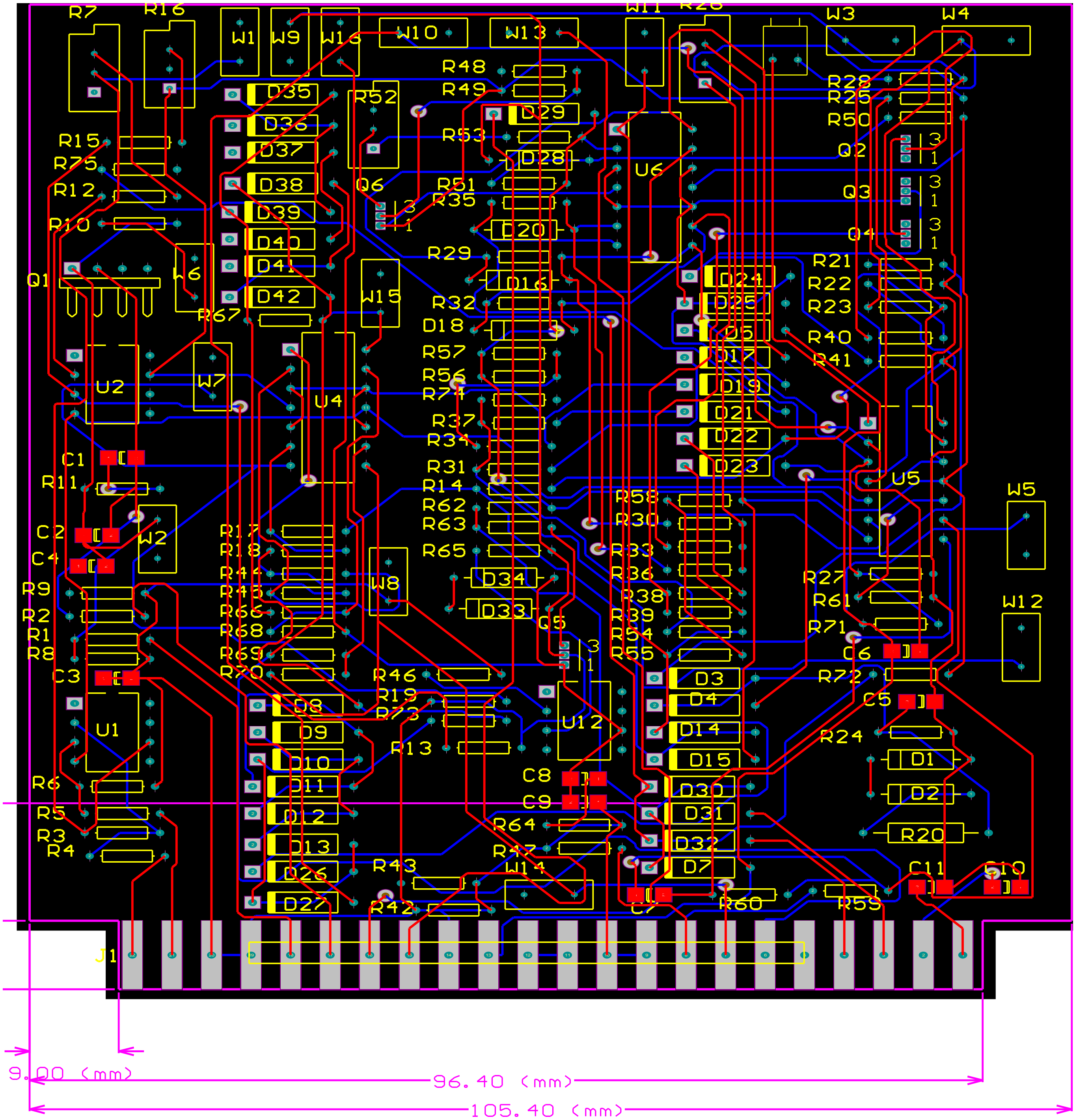


Fig10.16. *Motor Control Card PCB layout*

<u>PCB LAYOUT FOR INTERLOCK AND BRAKE CARD</u> :-

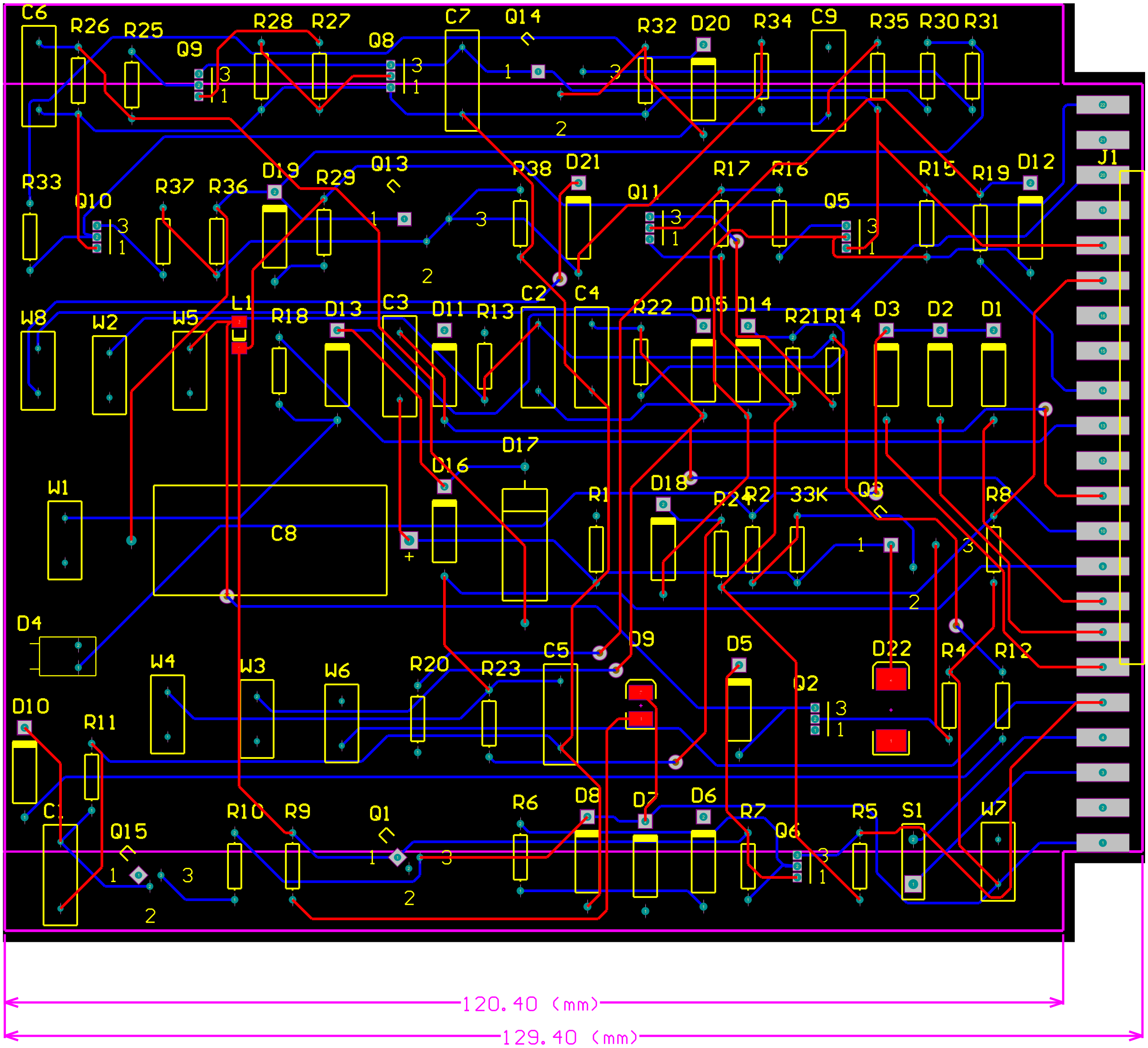


Fig10.17. *Interlock and Brake Card PCB layout*

11. FUTURE SCOPE

Presently brushed servo motors are being used in 29 antennas and brush-less servo motor is being used in the antenna C-4. Brushed motors are gradually becoming obsolete day by day because of their drawbacks. The limitations of brushed motors include lower efficiency and susceptibility of the commutator assembly to mechanical wear and tear and consequent need for servicing, at the cost of potentially less rugged and more complex and expensive control electronics. So it is planned to replace the brushed servo motors with brush-less motors in all 30 antennas.

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