MODELLING AND SIMULATION OF SERVO CONTROLLED ANTENNA SYSTEM

PROJECT REPORT

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

BACHELOR OF TECHNOLOGY

(Mechanical Engineering)

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ABSTRACT

This project attempts to provide the ground station antenna pointing mechanisms modeling, controlling and implementation for different Space Applications. The antenna position control is one of the issues that has drawn the researchers' attention to upgrade the control algorithm of the ground station antenna pointing system. The control station antenna should be directing to the satellite; such that the larger energy is captured from satellite Antenna. More specifically to ensure that the lobe of the satellite's antenna is in the direction of the lobe of the ground station's antenna, the satellite's antenna should be aligned with the satellite ground control station antenna to optimize the performance of a communications system. To ensure that the satellite antenna and the ground station antenna are aligned, the azimuth and the elevation angle of ground station antenna must be controlled. These both angles are defined as the antenna look angles. Look angles gives the required information. Currently available servo systems are used for antenna driving using the DC-motor. A complete mathematical Simulink model for the dynamics of the entire system of 7.5 m Antenna Ground Station including its servo control system has been developed using the PD-controller. The Ziengler-Nichols method is used to tune PD-controller gain value in simulink model of two links that represents the actual Antenna system. Here, the azimuth angle of the link-1 and elevation angle of link-2 are controlled. By using Bond graph methodology, a bond graph of 2-link system was made using the mathematical model. From this bond graph, The differential-algebraic equations (DAEs) are derived in state-space form. The simulink model of this mathematical model is simulated using the MATLAB R2015a. The better azimuth and elevation angle control is observed using the tuned PD-controller.

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Organization of Thesis

This thesis is organized in the following manner.

CHAPTER 1: INTRODUCTION

This chapter provides basic theory of working of Antenna and look angles. Benefits of bond graph methodology and scope of mathematical model of 7.5 m Antenna system has been explained.

CHAPTER 2: LITERATURE REVIEW

This chapter discusses the study of some research papers to get the brief idea about Antenna pointing mechanism, modelling the simulation, to study the bond graph method and implementation to the Space Applications.

CHAPTER 3: METHODOLOGY

This chapter provides the detailed discussion of the methodology followed in achieving the dual axis control of mathematical model of Antenna system. Bond graph methodology is used for mathematical model of two links. Theory of MATLAB Simulink is also discussed. Simulink model of two links is made in MATLAB Simulink.

CHAPTER 4: RESULTS AND DISCUSSION

This chapter discusses the results obtained by providing desired input angular velocity at both joints of two links in mathematical model. Desired and actual results were compared for both links.

CHAPTER 5: CONCLUSIONS AND FUTURE SCOPE

In this chapter, all steps for making of simulink model of two link mechanism has been concluded and further modifications that can be applied to improve the experimental setup are discussed.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The objective of the project is to make a mathematical model of the servo control antenna ground station using the bond graph approach.

Mathematical models are very useful for analyzing the system behaviour. Parabolic antennas mounted at earth stations are commonly used in satellite tracking applications. A mathematical model would be very useful if any upgradation in the system is to be done like if antenna load is changed , tracking accuracy is improved or if some new technology components are replaced by old one for better performance. A Bond Graph model for the dynamics of the entire Antenna Ground Station and its Servo Control System will be modeled. This will facilitate the modeling in multi-energy domains and provide insight into the causality aspects between interacting subsystems. The model will include the kinematics and dynamics, and the servo control system used to control the antenna. The system involves the simultaneous independent control of two axes of the antenna mechanism. The system may appear simple but involves couple dynamics of a gyroscopic nature due to rotations, which is not intuitive. The development of the model will facilitate dynamics of component subsystems and their power and causal interactions. The model can be represented in the form of ordinary differential equations. The model will be simulated using MATLAB.

1.2 ANTENNA ACTUAL SYSTEM

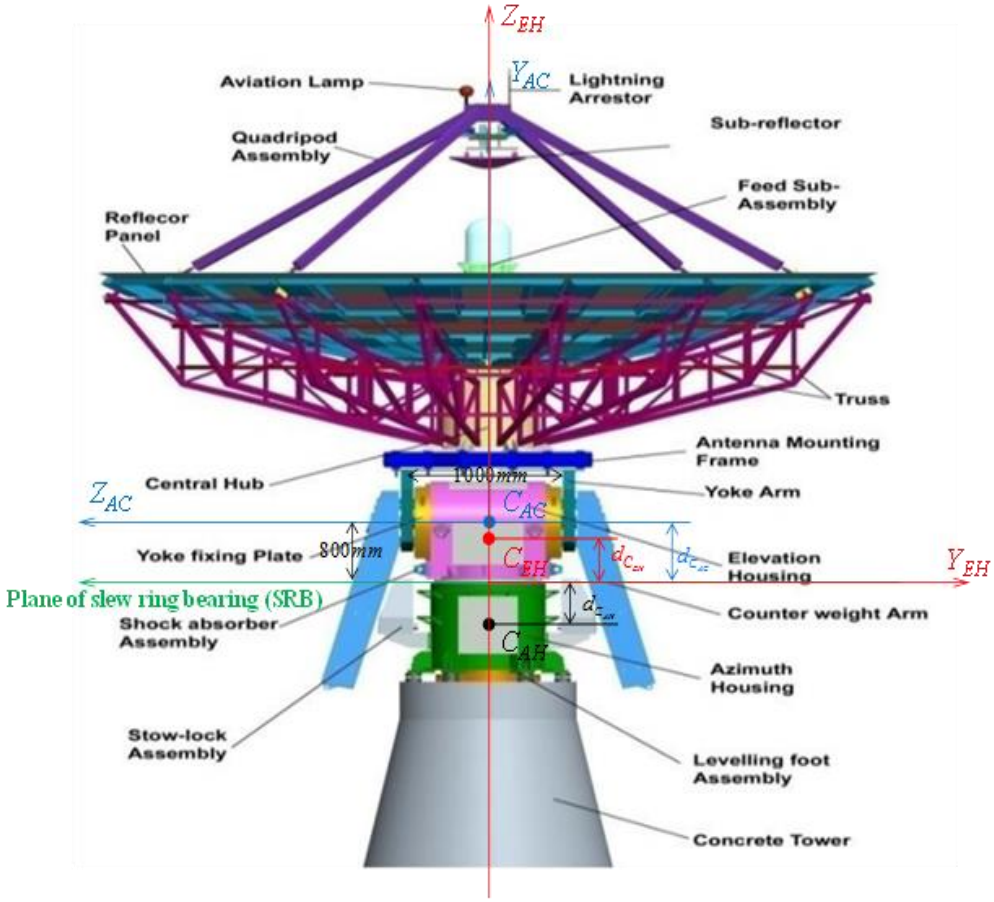

Figure 1-1 7.5 m antenna system

1.3 WORKING

A satellite dish is a dish-shaped type of parabolic antenna which is designed to receive or transmit data by radio waves from or to a communication satellite. If antenna is designed as a receiver, then information from satellites comes in form of electromagnetic waves. this radio signal has its specific frequency. That signal is first received in the bowl part of the antenna and then after reflecting from this part it goes into the subreflector of the antenna (the small part at the top). In subreflector, energy from that signal becomes focused and then it generates the analog signal which is used in some useful process. If antenna is designed as a transmitter then first analog signal is focused into subreflector then it is reflected by the reflector surface and then it is transmitted into space in form of electromagnetic waves. So Antenna can work as a

Transmitter or as a Receiver. As a Transmitter it receives an Electric Signal and converts it into electromagnetic waves. As a Receiver it receives an electromagnetic Waves and converts it into Voltage Signal.

Consider one positive charge and one negative charge placed a distance apart. This arrangement is known as a dipole as shown in figure 1-1. So they produce an electric field as shown. Now assume that this charges are oscillating as shown in figure 1-1, so in between their path, at the midpoint of their path velocity will be maximum and at the extreme point of their path velocity will be zero. The charged particles will have an acceleration and deceleration due to this velocity variation. By this mechanism electric field will vary and so it will produce varying magnetic field. So electromagnetic wave is generated and thus Propagation of Wave occurs. This principle is used in Antenna. As shown in figure 1-3 by taking a conducting rod with bend at the centre and applying time varying voltage signal at centre electromagnetic wave propagation and generation occurs.

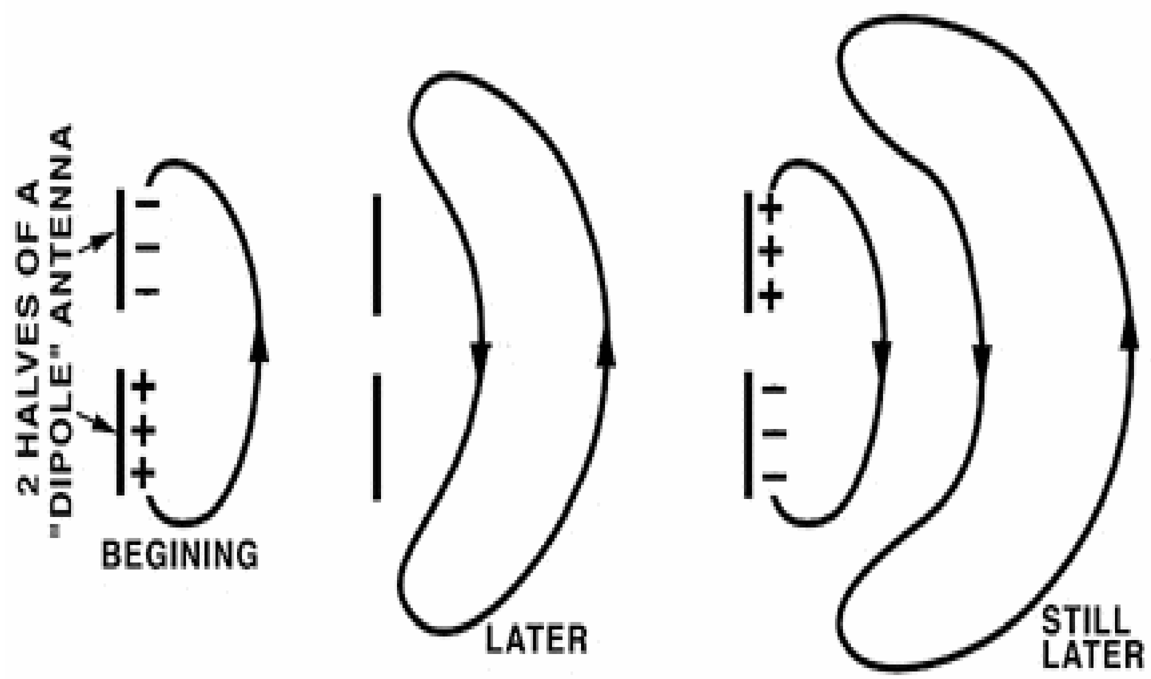

Figure 1-2 Wave generation and propagation mechanism by dipole

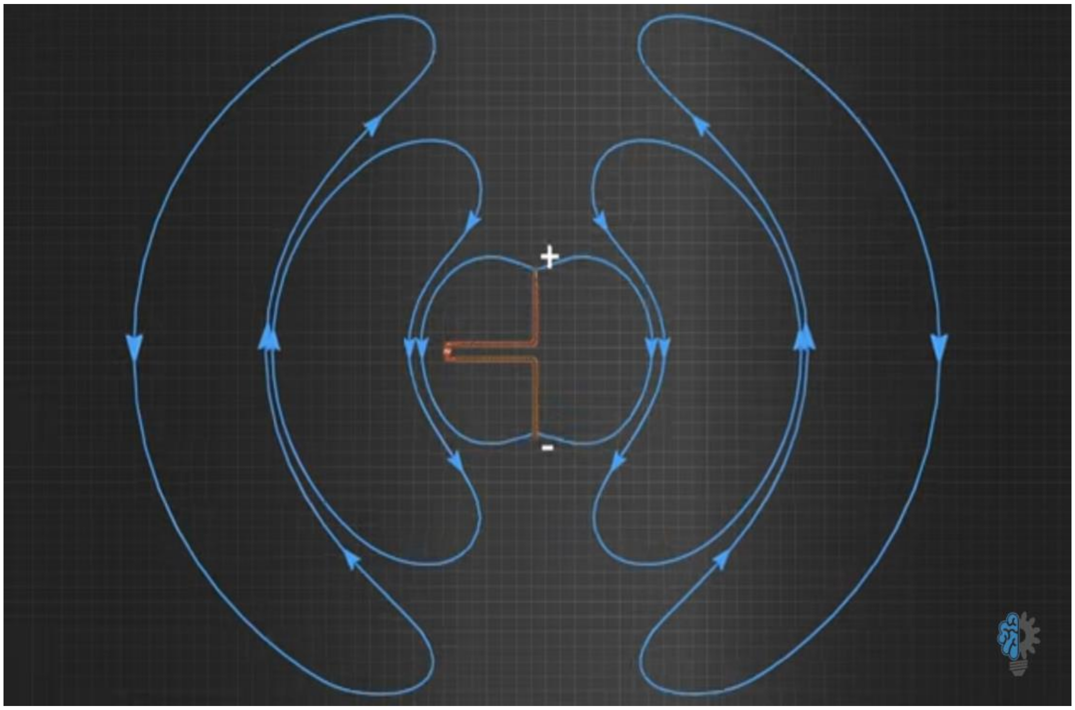

Figure 1-3 Electromagnetic wave generation in Antenna

1.4 LOOK ANGLES

The satellite Earth station antenna will receive the maximum signal when it is located directly under the satellite. It is necessary to maintain the position of the antenna so that it would receive the maximum signal from the satellite.

For **dual axis** antenna control two angles come into picture which are called look angles:

Azimuth Angle

Elevation angle

By changing these angles we can place the antenna in a particular position.These two angles are helpful in order to point at the satellite directly from the earth station antenna. So, the maximum gain of the earth station antenna can be directed at the satellite.

1.5 AZIMUTH ANGLE

Azimuth angle is the angle between local horizontal plane and the plane passing through earth station, satellite and center of earth. Azimuth refers to the rotation around a vertical axis. Azimuth tells us what direction to face. It is measured in degrees. Azimuth angle can change from 0 to 360 degrees. It is measured from North at 0° in the clockwise direction. So as we turn to our right (in a clockwise direction) then we will face East direction(which is at 90°) in diagram. So with respect to north direction, similarly at south azimuth angle is 180 degree and at west azimuth angle is 270 degree. In figure 1-4 satellite position is at somewhere between 0 and 90 degree azimuth angle. So it means that satellite is in the north-east direction of us.

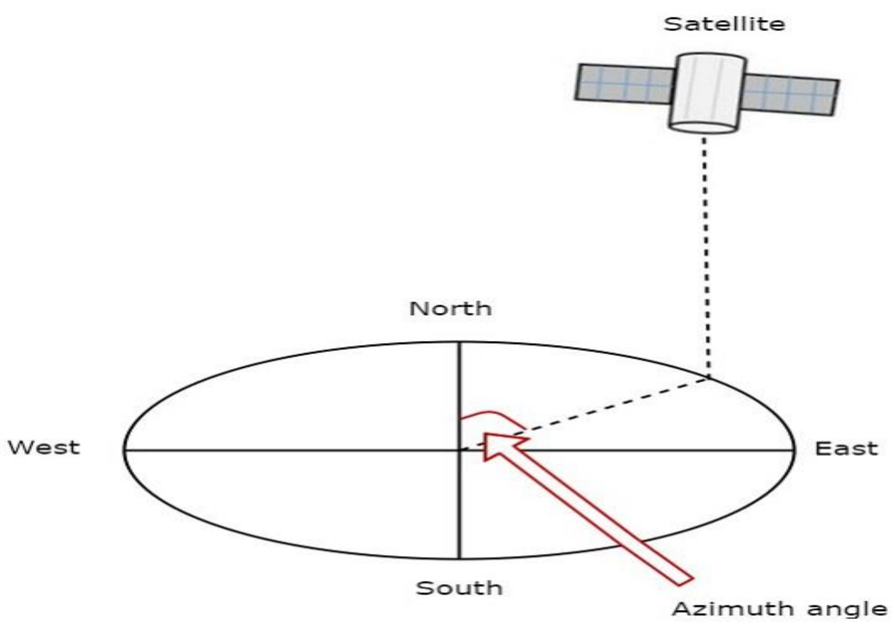

Figure 1-4 Antenna azimuth angle

If we measure the horizontal angle from north pole to the earth station antenna it will give us the azimuth angle.

1.6 ELEVATION ANGLE

Elevation angle is the angle between the line pointing direction towards the satellite and the horizontal plane. Elevation tells you how high up in the sky to look. It is also measured in degrees.

When the antenna points low down near the horizon the elevation angle is nearly zero. When the elevation angle is low the path followed through the atmosphere will be longer and the signal will degrade by the action of rain and other factors.When the antenna points straight up the elevation angle measures nearly 90°.When elevation angle is high there is a possibility of rain water accumulation in the antenna.

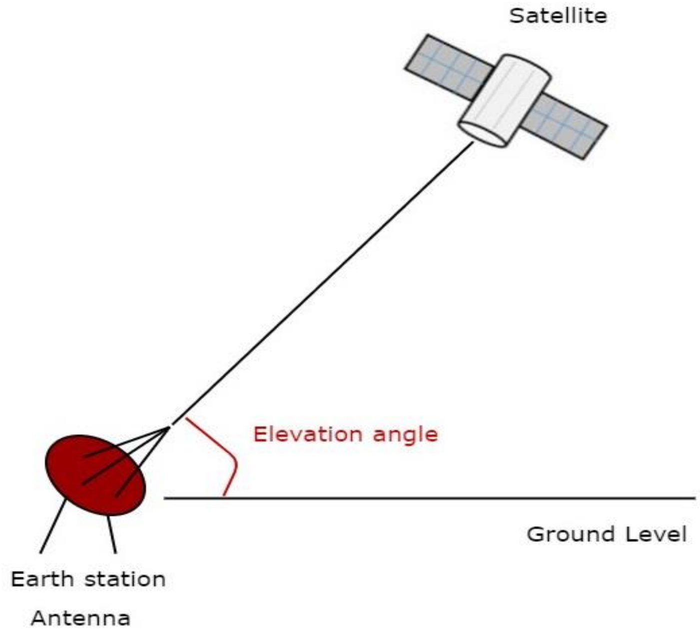

Figure 1-5 Antenna elevation angle

If we measure the vertical angle at earth station antenna from ground to satellite then it will give us the elevation angle.

CHAPTER 2

LITERATURE REVIEW

Research papers are studied to get the brief idea of antenna pointing mechanisms, modelling the simulation, to study the bond graph method and implementation to the Space Applications. The control station antenna should be directing to the satellite; such that the larger energy is captured from satellite Antenna look; angles gives the required information; more specifically to make sure that the lobe of the satellite's antenna is in the direction of the lobe of the ground station's antenna. The satellite's antenna should be aligned with the satellite ground control station antenna to optimize the performance of a communications system. To ensure that the satellite antenna and the ground station antenna are aligned, the azimuth and the elevation angle must be controlled properly. These both angles are defined as the antenna look angles.

2.1 Antenna control system

- (Ayansola,E,& Yinusa,2010) This paper describes the mathematical modelling of satellite ground control station's antenna look angles. They have used the MATLAB for the simulation of mathematical model of controller.
- (Rajni & amp; Murthy,2015) This paper describes the servo control system's designing, modelling and analysis for satellite ground station's antenna using the PID-controller. To get the better results, the FUZZY- controller is used for smooth control. Hardware test set up was made for testing the performance of the ground station antenna.
- (Uthman & amp; sudin, 2018) In this paper they have analyzed two controllers: (i) PID-controller; PID parameter gains are tuned using the Ziegler-Nichols method. (ii) State feedback controller; to meet transient response. To improve controller system, LQR(Linear Quadratic Regulator) is used with the PID-control.

- (Aloo, Kihato, & Kamau, 2016) This paper presents the Hybrid PID-LQR Controller to get the more pointing accuracy. The PID-controller and the Hybrid PID-LQR Controller is compared in this paper and it is shown that the Hybrid PID-LQR Controller gives the better results.

2.2 Bond graph methodology

A new systematic design and a multidisciplinary approach to design the ground station antenna require for Modern communication systems. To modify the ground station antenna's control systems, the bond graph methodology is used. Antenna's manipulator is made of links that undergo translation and rotational motion, which should be controlled.

- (Damic, Vjekoslav, & Majda Cohodar, 2006).This research work presents the approach to develop the mathematical model for controlling the antenna motion. The robotic arms are developed which represents a collection of finite element beams. The differential-algebraic equations(DAEs) are generated for the mathematical model of the system.
- (Mishra & Vaz, 2014) in this paper, they have applied rigid body mechanics for teeter toy. Bond graph methodology is used for modelling. Equations from bond graph is derived. The model has been simulated by generating the code directly from the bond graph.
- Apart from this the references (5), (6) and (7) (as shown in reference) are studied for more understanding the dynamics of rigid body and the bond graph method.

CHAPTER 3

PRESENT WORK OR PLAN OF WORK

3.1 DESIGN METHODOLOGY

3.1.1 BOND GRAPH METHODOLOGY

Nowadays, in engineering, many systems are complex and in design many systems are made from different engineering principles and require complex methodology to solve it. so we use Bond graph methodology for solving this type of multidisciplinary systems. This approach offers an alternative to the conventional energy based methods. In Bond graph approach, we derive equations from bond graph in state space form. Even if system is multidisciplinary, we can also make bond graph of that system to solve it so it makes it easier to understand any system. Our system has multi-energy domain. For modelling of our system we are using bond graph approach.

3.2 BOND GRAPH MODELLING AND SIMULATION

We represents dynamics of any complex multidisciplinary system by making its bond graph. In bond graph power is transmitted through each bond. There are two power variables in bond graph- effort and flow. So power is the multiplication of effort and flow. For example, suppose there is bond graph of mechanical and electrical system. So this is multidisciplinary system. So in mechanical part, power = force x velocity, so here force is effort and velocity is considered as flow. For electrical part, power=voltage x current, so here voltage is effort and current is flow.

So this is the way we divide variables which are responsible for producing power in terms of effort and flow. So that it makes complex system easier to solve.

Mathematical model of two link mechanism is shown in (figure 3-1) below. It consists of two links. This two links are in cylindrical shape. 1^{st} link which is mounted on base such that it can only rotate about its z axis(z1) and 2^{nd} link which is connected to 1^{st} link which can rotate about its z axis(z2).

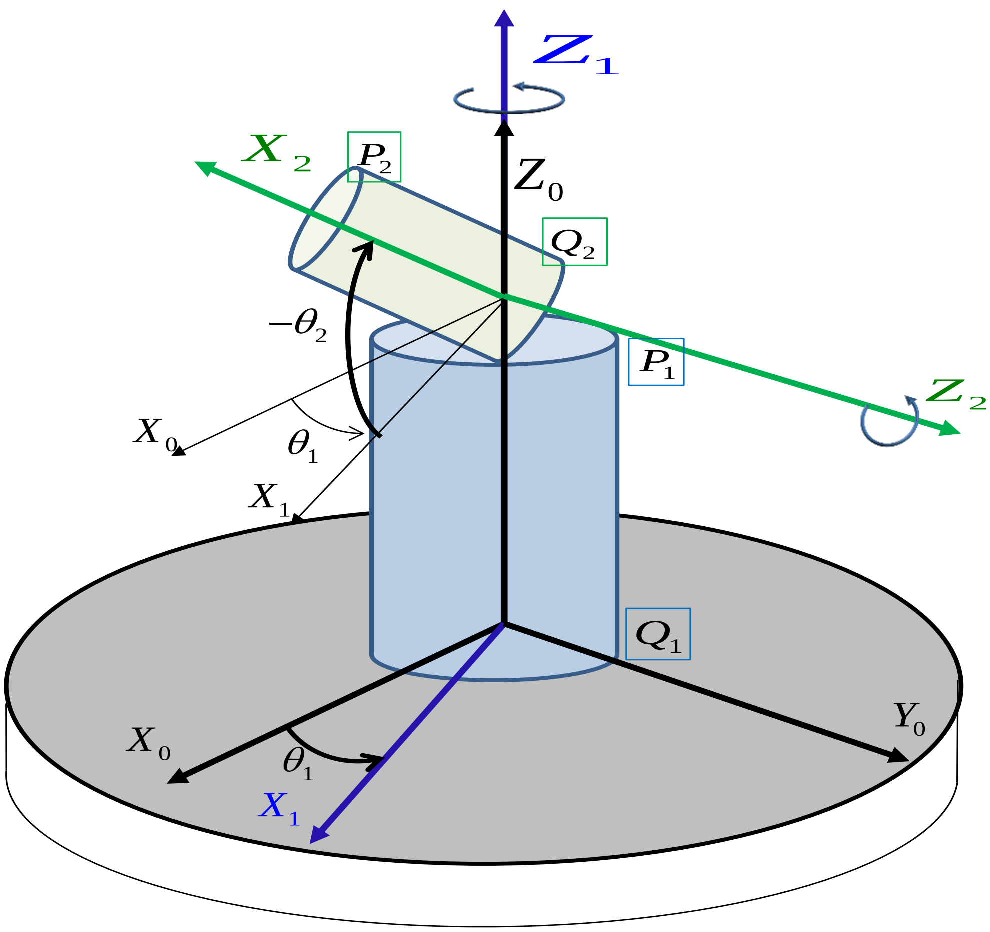

Figure 3-1 Two link mechanism

Rotational matrix for link 1:

$$[{}^{0}_{1}R]=\begin{bmatrix}\cos\theta_1 & -\sin\theta_1 & 0\\ \sin\theta_1 & \cos\theta_1 & 0\\ 0 & 0 & 1\end{bmatrix}$$

Rotational matrix for link 2:

$$[{}^{1}_{2}R]=\begin{bmatrix}\cos\theta_2 & -\sin\theta_2 & 0\\ 0 & 0 & -1\\ \sin\theta_2 & \cos\theta_2 & 0\end{bmatrix}$$

$$[{}^{0}_{2}R]=[{}^{0}_{1}R][{}^{1}_{2}R]$$

3.2.1 BOND GRAPH OF TWO LINK SYSTEM

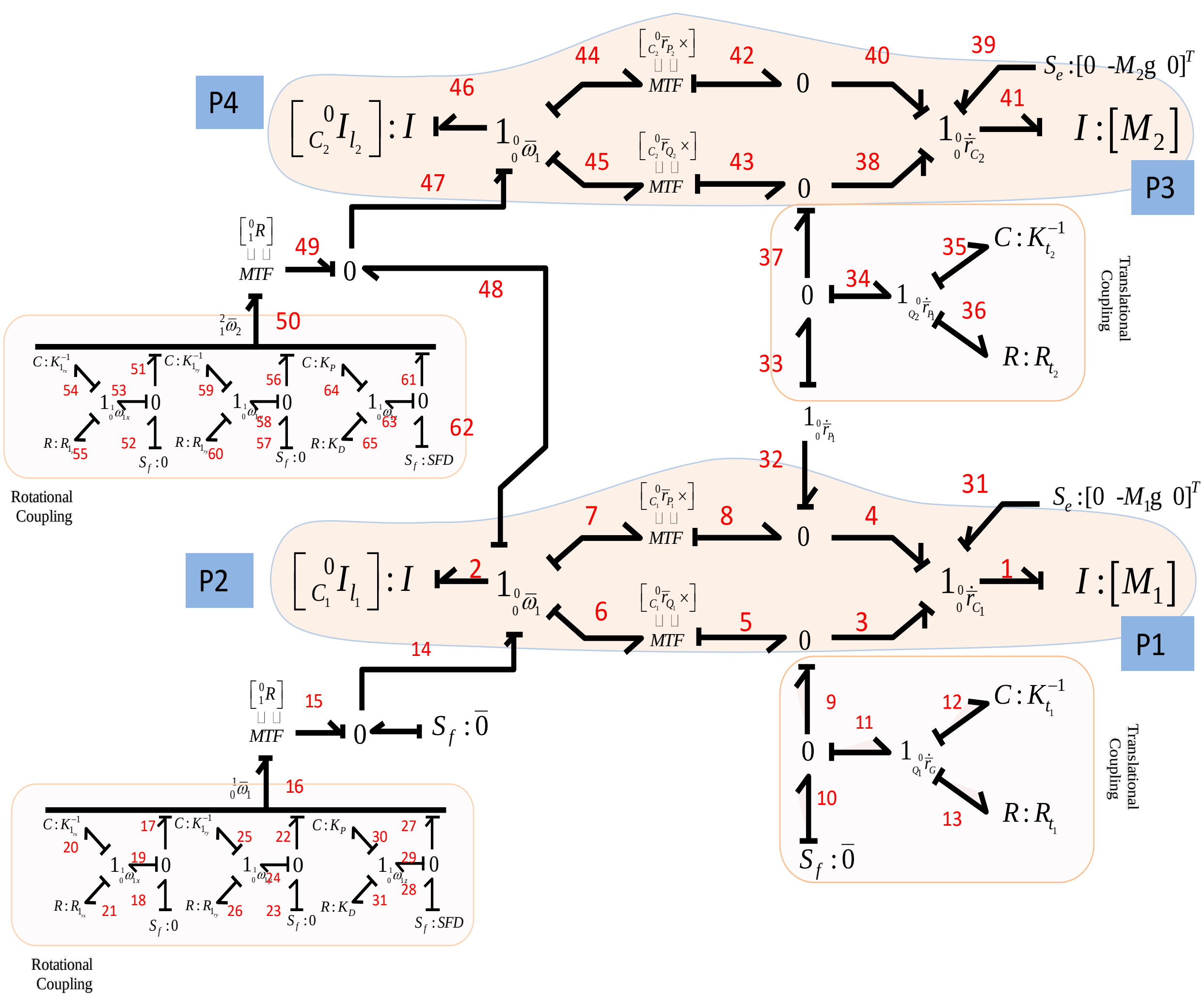

Figure 3-2 Bond graph of two link mechanism

Bond Graph of two link mechanism is shown (in figure 3-2). It consists of rotational couplings and translational couplings of two links. Two translational couplings are for restricting translational motion at both joints P1 and Q1. Rotational couplings in x and y direction restrict the motion for both links about x and y axis and it allows motion about z axis(Z1 and Z2) of both links. Similarly Translational couplings for both links restrict the motion in x, y and z direction. Bond graph of two link mechanism has been modeled and dynamic equations of the system are written using the bond graph approach.

3.3 MATLAB SIMULINK

Simulink was developed by mathworks. In matlab there is simulink library browser in which there are different types of blocks which is used in all engineering disciplines for modeling and simulation purpose. Some of the examples of these blocks are:-aerospace blockset, robotics system toolbox, control system toolbox, fuzzy logic toolbox, etc. there are also some blocks for doing different types of math operations, for generating different types of signal source, for displaying output in different ways, etc. so for example if we want to do simulation of any aerospace engineering system then we should use aerospace blockset with other required blocks.

So In final simulink model of any system, there are two types of elements in simulink: Blocks and Lines. Blocks are used to generate, modify, combine, output, and display signals. Lines transfer signals from output terminal of one block to input terminal of another block. in scalar 1d system we obtain single value as an output at every lines and in 3d system we have an output of order 3x1 at every lines.

So in MATLAB SIMULINK equations from bond graph has been plotted in form of block diagram which represents dynamics of two link mechanism. By running this Simulink model azimuth angle of 1st link and elevation angle of 2nd link has been controlled.

3.3.1 MATLAB SIMULINK MODEL OF TWO LINK SYSTEM

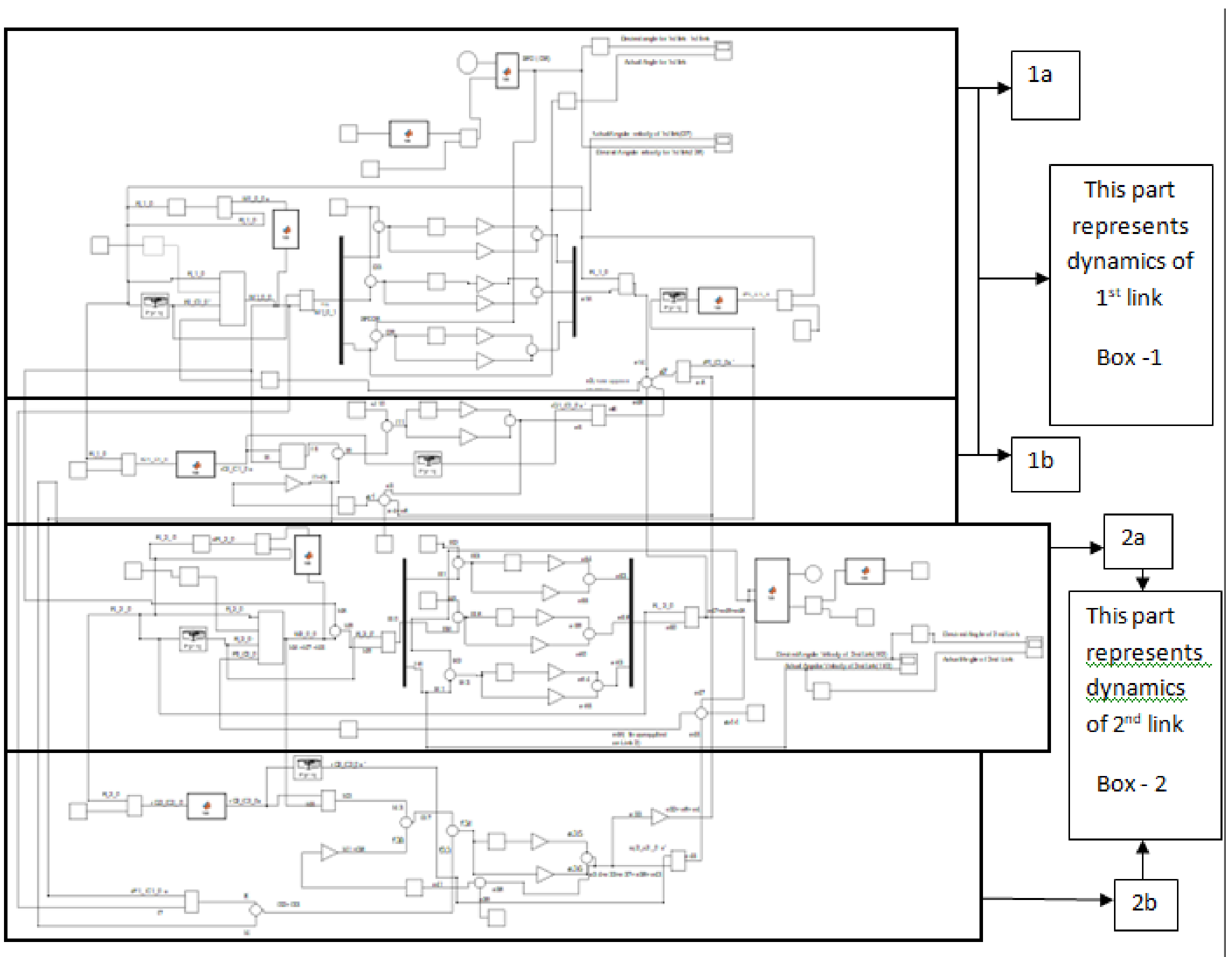

Figure 3-3 Simulink model of two link system

Complete Simulink model of two link mechanism is shown in figure 3-3. This model has been made by deriving equations from bond graph and plotting those equations in simulink. Simulink model is divided into two parts: box 1(upper half part) and box 2(lower half part). Box 1 represents the dynamics of 1st link. It has two sub parts 1a and 1b. Similarly box 2 represents the dynamics of 2nd link. It has two sub parts 2a and 2b. zoom in view of all subparts of simulink model has been shown below.

Part 1a

Part 1a represents rotational motion of 1st link. It has 3 couplings in respective x, y and z directions. Coupling consists of spring element and damper element. Link 1 can rotate only about its z axis(z1), so this coupling only restricts motion in x and y direction. Figure 3-4 shows zoom in view of part 1a.

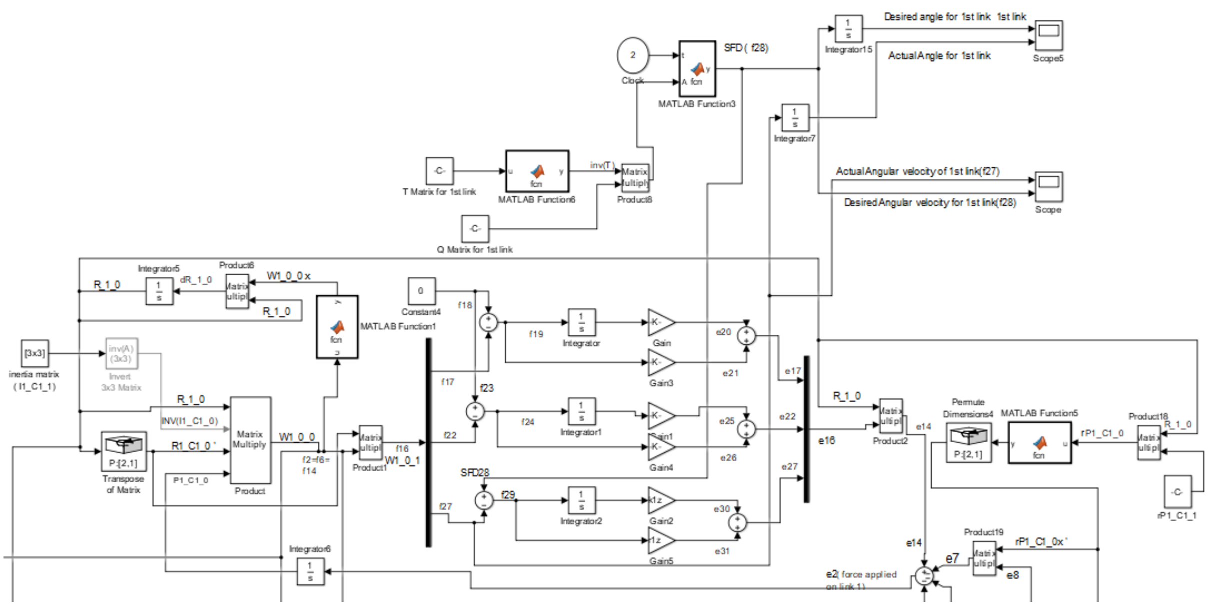

Figure 3-4 Zoom in view of part 1a

Part 1b

Part 1b represents translational motion of 1st link. It has 3 couplings in respective x, y and z directions. Link 1 can't move in either of its three directions x, y and z. So this coupling restricts motion in all direction. Figure 3-5 shows zoom in view of part 1b.

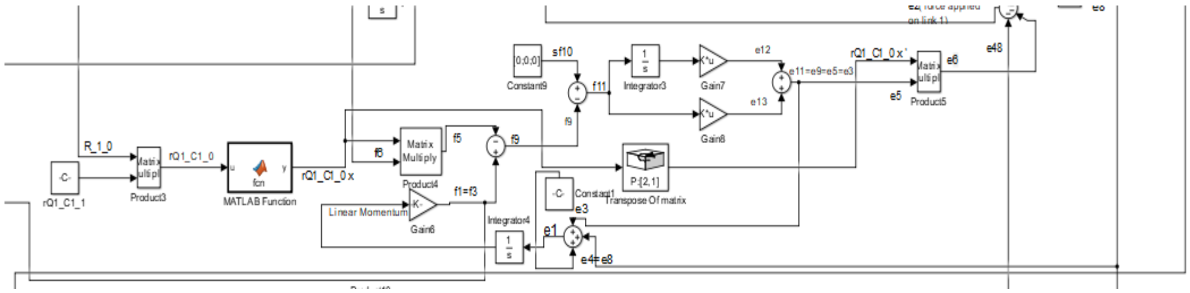

Figure 3-5 Zoom in view part 1b

Part 2a

Part 2a represents rotational motion of 2nd link. It has 3 couplings in respective x, y and z directions. Coupling consists of spring element and damper element. Link 2 can rotate only about its z axis(z2), so this coupling only restricts motion in x and y direction. Figure 3-6 shows zoom in view of part 2a.

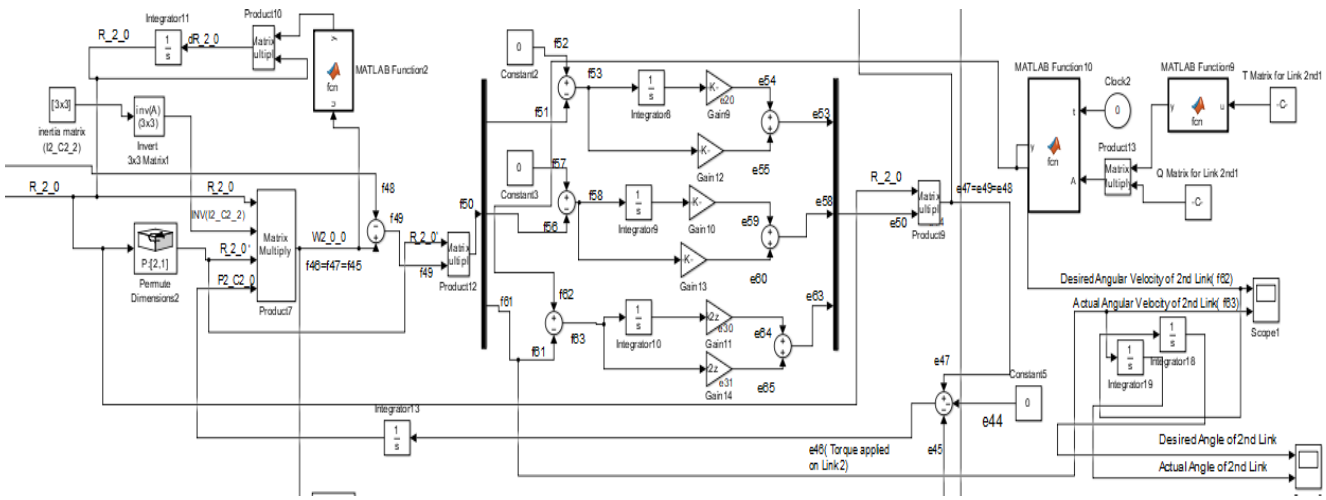

Figure 3-6 Zoom in view of part 2a

Part 2b

Part 2b represents translational motion of 2nd link. It has 3 couplings in respective x, y and z directions. Link 2 can't move with respect to link 1 in either of its three directions x, y and z. So this coupling restricts motion in all these 3 direction. Figure 3-7 shows zoom in view of part 2b.

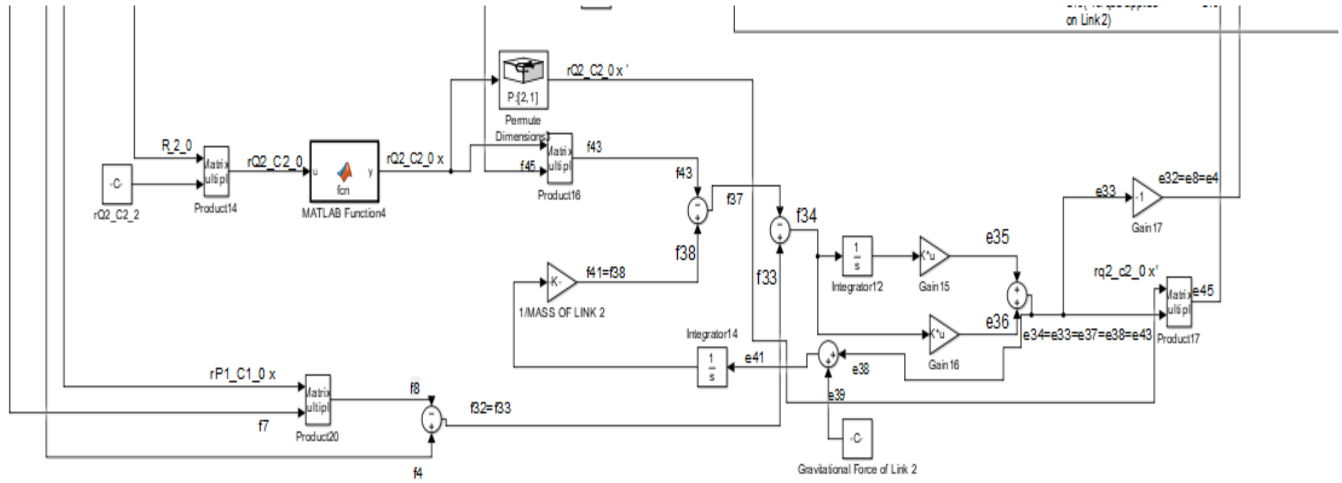

Figure 3-7 Zoom in view of part 2b

3.4 Ziegler-Nichols Method

This method is used in tuning a PID Controller. There is table which is provided by Ziegler and Nichols which gives value of K_p, K_i and K_d. K_p is proportional gain, K_i is integral gain and K_d is derivative gain. Table provides value of these 3 gains for different types of controller like P, PI, PD, PID. In our system we have used PD controller for controlling rotational and translational motion of two links. So table 3-1 for PD controller is given below.

Table 3-1 value of gains for PD controller

Controller Type	K_p	K_d
PD	$0.8K_u$	$(K_uT_u)/10$

In this method, first we put K_i and K_d gains value to zero. Then we increase value of K_p from zero until it reaches the value of ultimate gain K_u. This value of K_u is the largest gain at which output of the control loop will come stable and will have stable oscillations. If we use higher gain than K_u then it will have diverging oscillations which is unstable output. T_u is the time period for completing one cycle at which oscillations become stable. So from K_u and T_u, we have got value of K_p and K_d by using table 3-1. At these values of gains(as shown in table 3-2) error between desired and actual results for system was minimum.

Table 3-2 Calculated value of gain K_p and K_d for both links

Link	K_{pz}(in Z direction axis Z1)	K_{dz}(in Z direction axis Z2)
1^{st}	2000000	20000000
2^{nd}	3000000	80000000

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Simulation results of simulink model of two link using ode15s solver

4.1.1 Response of system by providing desired input

We are providing simultaneous desired angular velcity to both the links for 2 sec and defining the initial azimuth angle as 0 degree and final as 360 degree for 1^{st} link and the initial elevation angle as -20 degree and final as 190 degree for 2^{nd} link. Parameters like mass, length and moment of inertia of links in 3 directions of actual 7.5 m antenna system were used in simulink model of two links mechanism from MATLAB code of actual Antenna system. Final simulation results were plotted, which is shown below.

Variation of desired and actual angular velocity of 1^{st} link:

From bond graph(as shown in figure 2-2), f28 is desired angular velocity and f27 is actual angular velocity. From figure 4-1 we can see that actual angular velocity is same as desired angular velocity of 1st link.

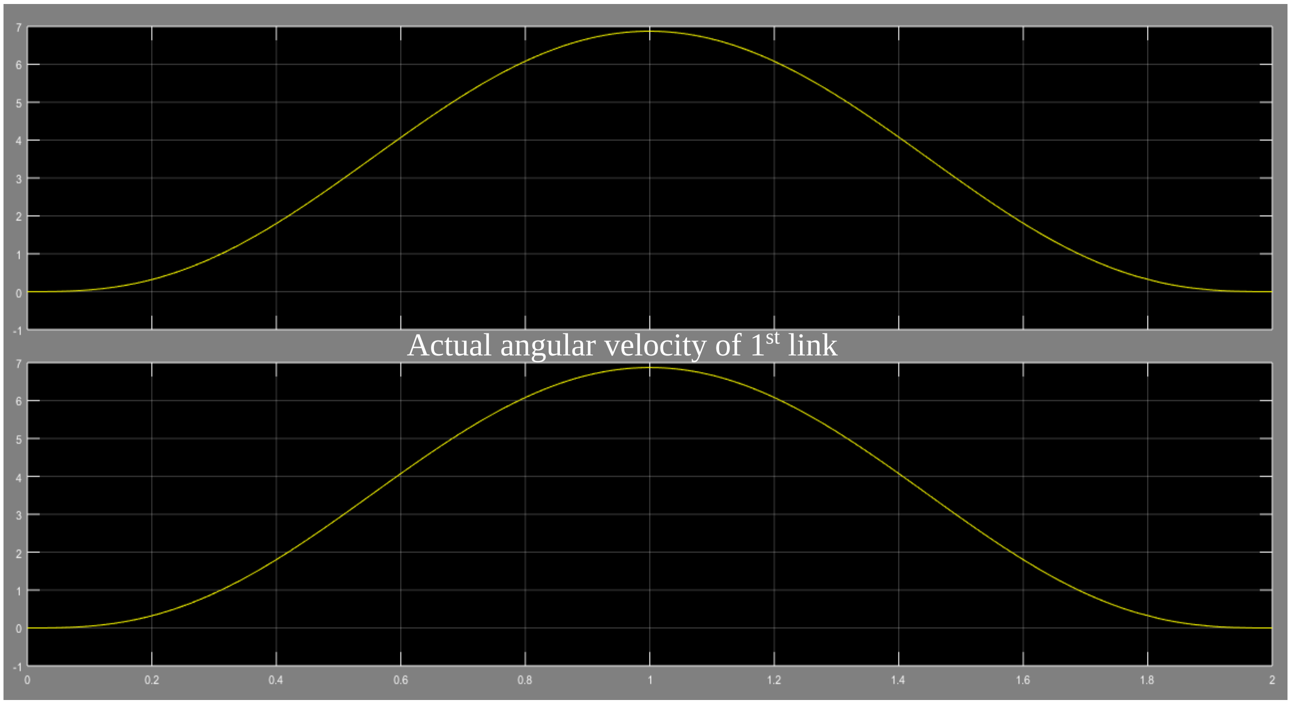

Figure 4-1 Angular velocity of 1st link vs time

Variation of desired and actual angular velocity of 2nd link:

From bond graph(as shown in figure 2-2), f62 is desired angular velocity and f61 is actual angular velocity. From figure 4-2 we can see that actual angular velocity is same as desired angular velocity of 2nd link.

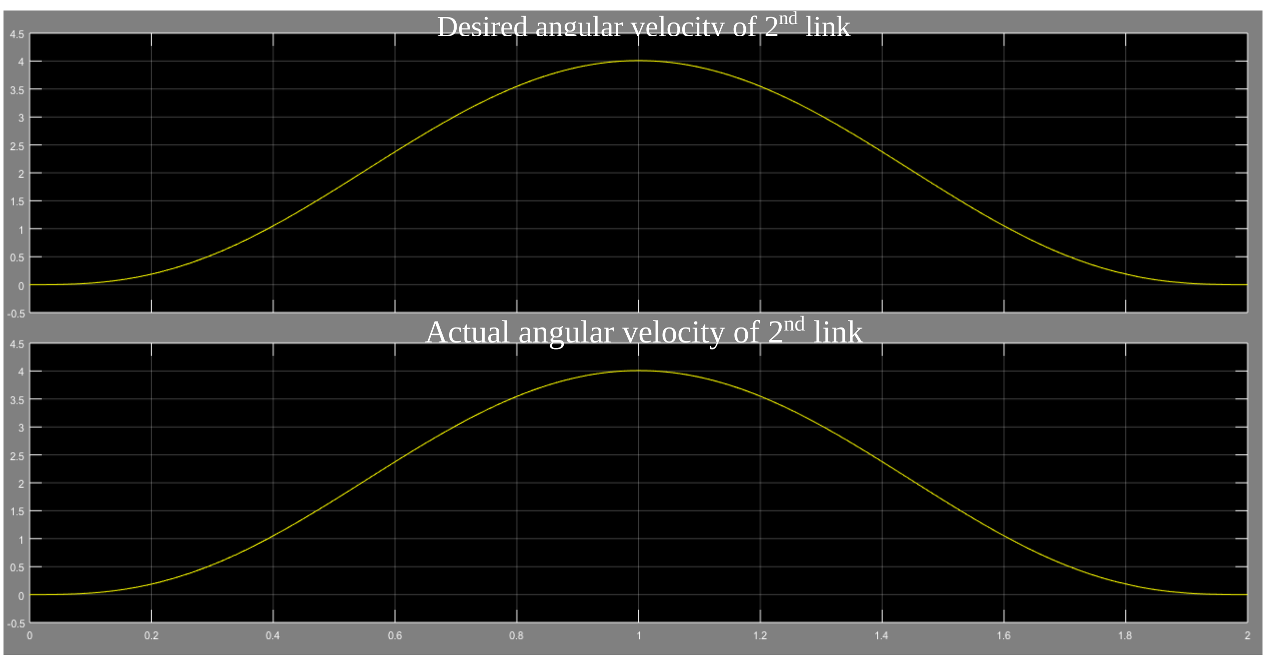

Figure 4-2 angular velocity of 2nd link vs time

Variation of desired and actual angular position of 1st link:

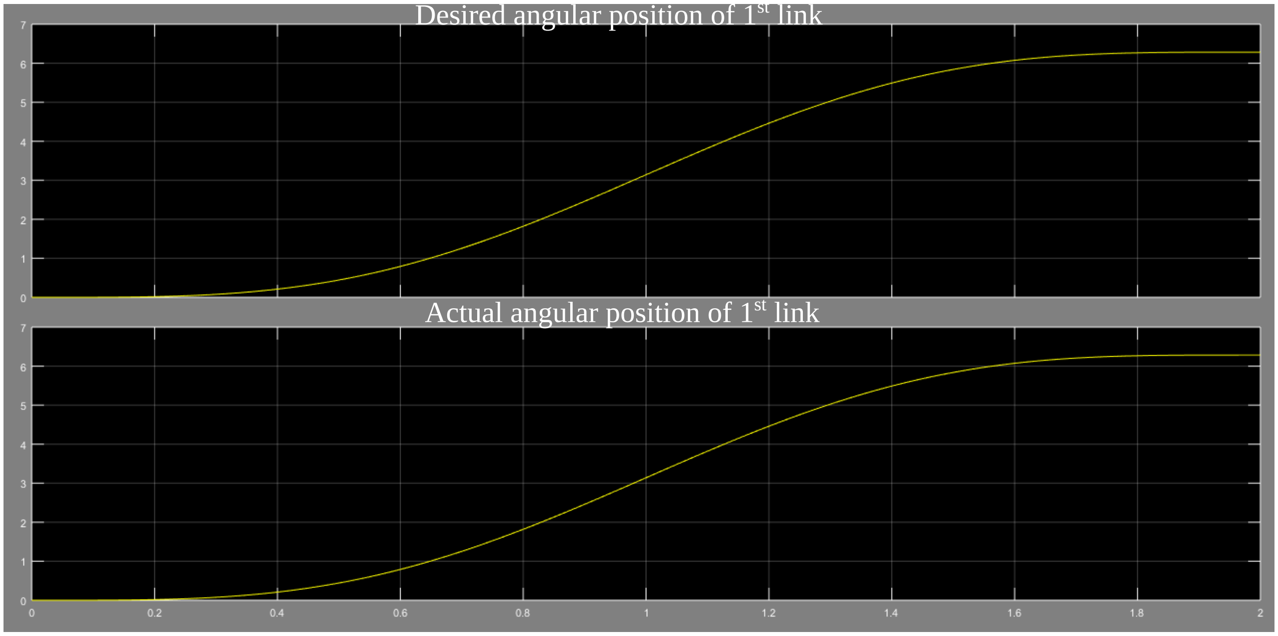

Figure 4-3 angular position of 1st link vs time

Variation of desired and actual angular position of 2nd link:

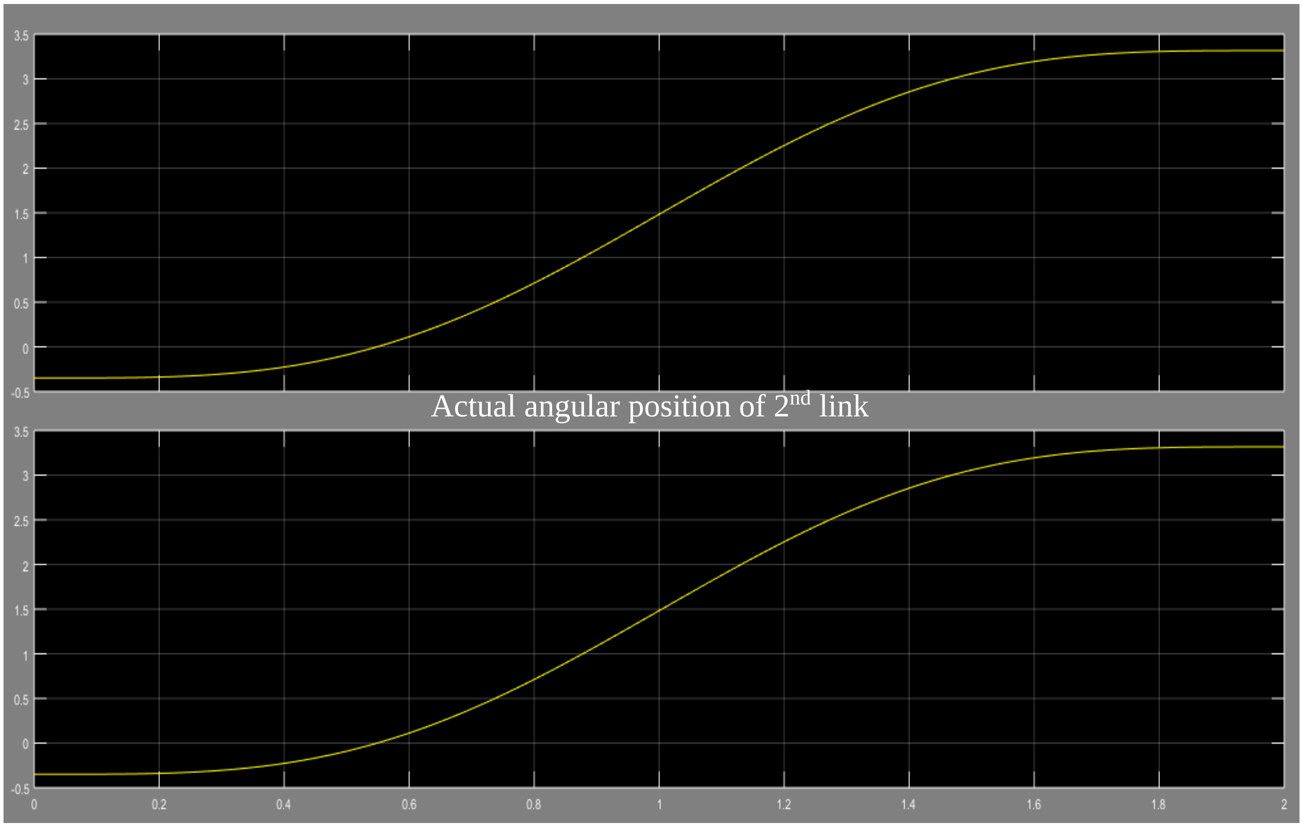

Figure 4-4 angular position of 2nd link vs time

From figure 4-3 and 4-4 we can see that desired and actual angular position of both links are coming same. So error between actual and desired angular position is zero or minimum.

Variation of torque produced at join P1 of link 1 at base with time:

This is graph of torque produced (as shown in figure 4-5) along z direction (z1) of link 1. From this torque we can select motor of required specification which is used at joint of 1st link with ground base so that azimuth angle of 1st link will change accordingly.

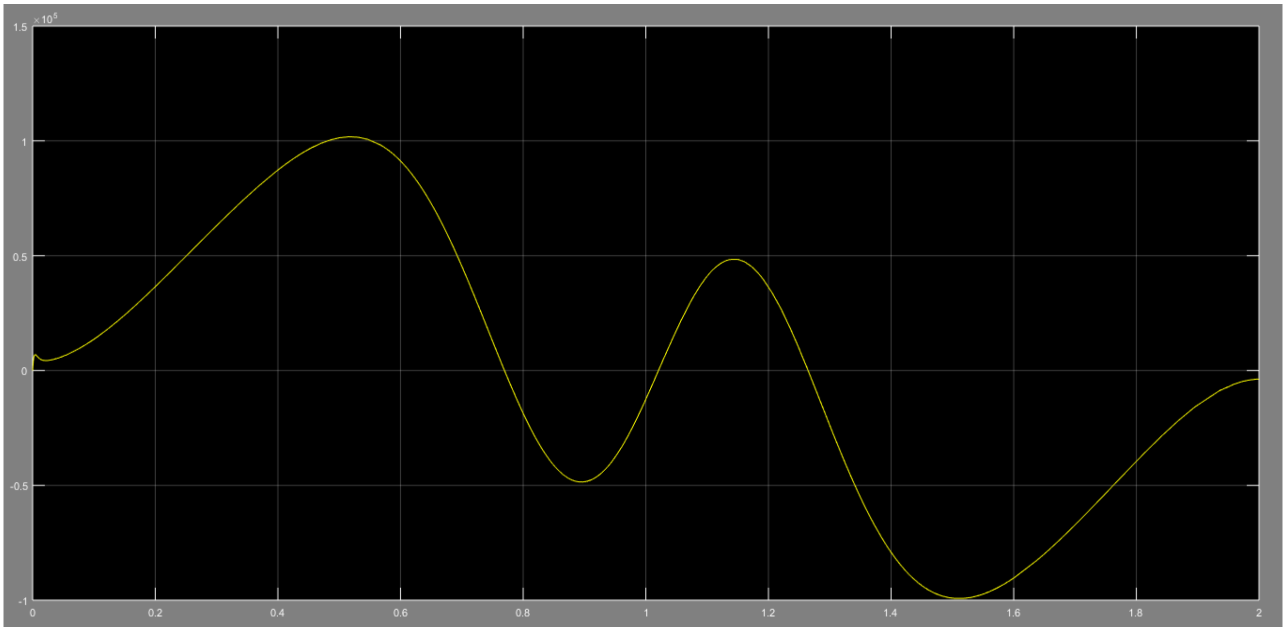

Figure 4-5 torque produced at joint P1 of 1st link vs time

Variation of torque produced at joint Q1 between link 1 and link 2 with time:

This is graph of torque produced (as shown in figure 4-6) along z direction (z2) of 2nd link. From this torque we can select motor of required specification which is used at the joint between two links so that elevation angle of the 2nd link will change accordingly.

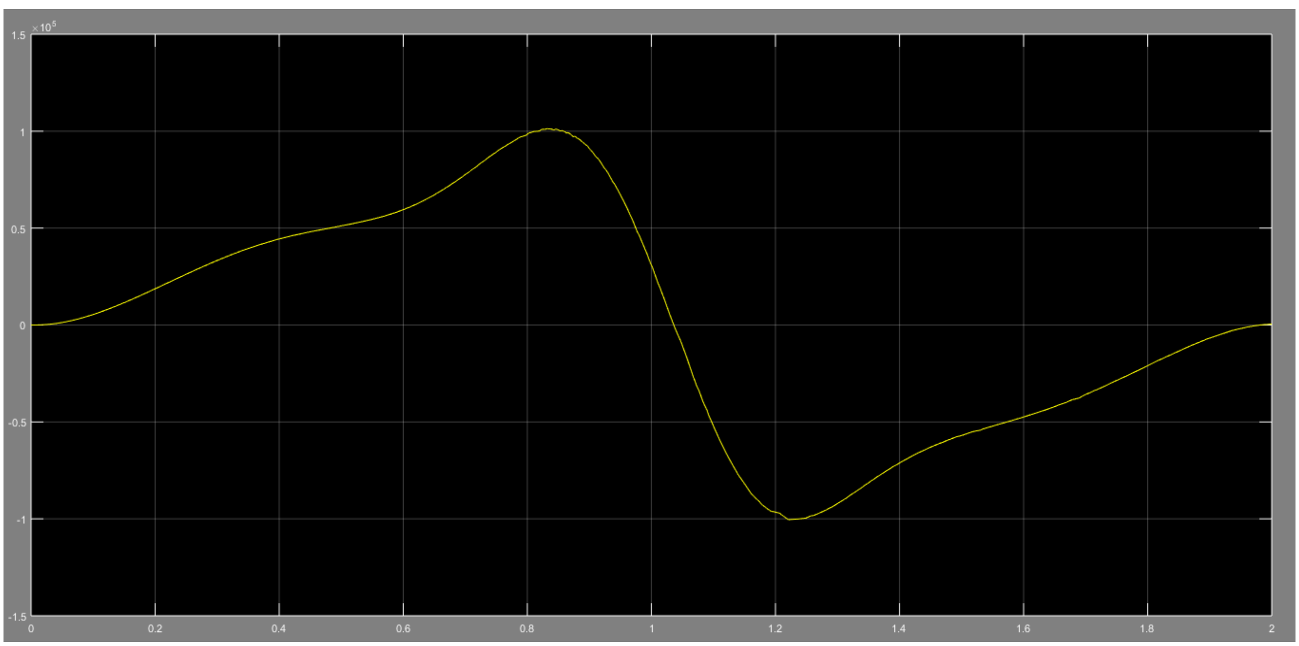

Figure 4-6 torque produced at joint between two links vs time

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSION

A complete mathematical simulink model for the dynamics of the entire system of 7.5 m Antenna Ground Station including its servo control system has been developed. First of all we have made mathematical model of two links mechanism that represents actual Antenna system. By using Bond graph methodology, bond graph of this system was made. From this bond graph, system equations were derived in state-space form. This equations were plotted in form of blocks and lines in MATLAB Simulink. By putting value of dimentions and all parameters of actual Antenna system in this simulink model, final simulation results were plotted. Those results are;

- Variation of desired and actual angular velocity of both links
- Variation of desired and actual angular position for both links
- Torque produced at joint of link 1 with base
- Torque produced at joint between link 1 and link 2

By this result we can select required specification of motor for actual antenna system that will help to control azimuth and elevation angle of two links such that the larger energy is captured from satellite Antenna.

5.2 SCOPE OF PROJECT

- Such a Simulink model will be very helpful to assess the system performance whenever a component like motor is replaced with a different model during upgradation of system, or some system parameter like antenna load or tacking accuracy are changed or some advance controller (like LQG controller) is used in place of/in addition to PID controller to counter wind gust effects on tracking accuracy of the antenna.
- The model has been simulated using MATLAB Simulink. Parameters used in the model may be varied, so one can perform simulation by changing value of parameters. The simulation may be performed by varying lengths of time.

- This mathematical model would be generic in nature and could also be used for other systems as well by simply changing the parameters in the existing model.
- The model will include the kinematics and dynamics, and the servo control system used to control the antenna. The dynamics of the drives and transmission is also proposed to be included.

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