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# Revolutionizing Satellite Tracking: A Double Actuator System for Precise and Efficient Antenna Pointing Control

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**Abstract :** This study presents a double actuator model consisting of a DC motor plus lead screw in series with a piezoelectric stack (PZT). The DC motor and lead screw combination provide large displacements, while the PZT stack offers fast and precise positioning. The model was tested for antenna pointing control when tracking a satellite, where large amplitude motion with time constants measured in a few seconds is required to move between satellites, and fine control is required to track a given non-geostationary satellite. The control system uses the PZT stack and the DC motor together to track the reference signal, allowing for efficient and precise actuation. The linearization of the system and analysis of its frequency response provide valuable insights into the system's behavior, stability, and performance, and can help optimize its performance for specific applications. The results demonstrate that the double actuator model offers a promising solution for precise and efficient actuation in various applications, including robotics, aerospace engineering, and medical devices. Further research in this area is warranted to develop more efficient and effective actuation systems.

**Keywords:** Double actuator system, DC motor, lead screw, piezoelectric stack, satellite tracking, antenna pointing control, precise positioning, efficient actuation, frequency response, linearization

## 1. Introduction

Actuators play a vital role in various engineering applications, including robotics, manufacturing, and medical equipment. The performance of an actuator is crucial to the success of a system, and therefore, researchers continuously strive to develop new technologies to improve actuator performance. One such development is the double actuator, which combines the benefits of two different actuator technologies to create a more efficient and effective system. In this paper, we discuss a double actuator consisting of a DC motor plus lead screw in series with a piezoelectric stack. The DC motor and lead screw combination are known for their ability to support large displacements, making them ideal for high load applications. However, the dynamic response of this combination is relatively slow when tracking reference demands. On the other hand, piezoelectric stacks are known for their fast dynamic response but can only support a limited range of displacements. By combining these two actuator technologies, we create a large stroke actuator with highly precise positioning.

The double actuator proposed in this paper has a unique design that allows for the piezoelectric stack to be used as a high-frequency displacement corrector. The DC motor and lead screw combination provide the necessary displacement range, while the piezoelectric stack corrects any errors in real-time, resulting in precise positioning of the actuator. The use of double actuators has been investigated in various engineering applications, including precision machining and medical equipment. In precision machining, double actuators have been used to improve the accuracy and precision of machining operations. In medical equipment, double actuators have been used to create more efficient and effective devices for drug delivery and surgical procedures.

## 2. Literature Review

Piezoelectric materials, such as lead zirconate titanate (PZT), have been widely used in the field of actuators due to their ability to convert electrical energy into mechanical displacement. PZT actuators have a high dynamic response and excellent precision, making them suitable for various applications such as precision positioning, vibration control, and flow regulation. In this literature review, we discuss some recent advancements in the development and application of PZT actuators. One of the significant challenges in the development of PZT actuators is the hysteresis effect, which leads to nonlinear behavior and reduces the accuracy of the actuator. Several studies have investigated ways to compensate for the hysteresis effect in PZT actuators. For example, Yan et al. (2019) proposed a new model-based feedforward control scheme to compensate for hysteresis in PZT actuators, which significantly improved the accuracy of the actuator. Another important aspect of PZT actuators is their ability to generate large displacements. Several studies have investigated the use of PZT actuators in various applications that require large displacement, such as micropositioning and ultrasonic motors. Wu et al. (2019) proposed a new design for a piezoelectric rotary ultrasonic motor that utilizes a PZT actuator to generate a large displacement and high torque. The proposed motor achieved a high efficiency and low noise, making it suitable for various applications. PZT actuators have also been used in the field of active vibration control. Active vibration control systems utilize PZT actuators to generate vibrations that cancel out unwanted vibrations in a system. Huang et al. (2020) proposed a new adaptive active vibration control system that utilizes a PZT actuator and an adaptive controller to cancel out vibrations in a flexible beam. The proposed system achieved a significant reduction in vibration amplitude and showed good robustness to external disturbances. PZT actuators have also been used in the field of microfluidics. PZT actuators can be used to regulate fluid flow in microfluidic channels, which is important for various applications such as drug delivery and microreactors. Wang et al. (2020) proposed a new design for a microfluidic flow control system that utilizes a PZT actuator to regulate the fluid flow. The proposed system achieved a high accuracy and fast response, making it suitable for various microfluidic applications.

In addition to the above-mentioned applications, PZT actuators have also been used in the field of optics. PZT actuators can be used to control the shape of optical elements such as mirrors and lenses, which is important for applications such as adaptive optics and laser beam shaping. Li et al. (2020) proposed a new design for an adaptive optics system that utilizes a PZT actuator to control the shape of a deformable mirror. The proposed system achieved a high accuracy and fast response, making it suitable for various applications such as astronomical observations. Another important application of PZT actuators is in the field of MEMS (micro-electromechanical systems). MEMS devices utilize microscale actuators to control the motion of microscale structures, and PZT actuators are a popular choice due to their high precision and fast response. Wang et al. (2021) proposed a new design for a MEMS tunable filter that utilizes a PZT actuator to control the position of a microscale mirror. The proposed filter achieved a high tuning range and low insertion loss, making it suitable for various applications such as optical communications. One of the challenges in the development of PZT actuators is the mechanical fatigue that occurs when the actuator is subjected to repeated cycles of loading and unloading. Several studies have investigated ways to improve the fatigue resistance of PZT actuators. For example, Zhou et al. (2021) proposed a new design for a PZT actuator that utilizes a multilayer structure to improve the fatigue resistance of the actuator.

Another challenge in the development of PZT actuators is hysteresis, which refers to the difference in response between increasing and decreasing input voltages. Hysteresis can cause errors in positioning and motion control applications. Various approaches have been proposed to reduce hysteresis in PZT actuators, such as the use of adaptive control algorithms and compensation techniques (Chen et al., 2019; Deng et al., 2020). PZT actuators have also been integrated with other actuator technologies to create double actuators with improved performance. For example, the double actuator consisting of a DC motor plus lead screw in series with a PZT stack described in the previous section combines the large displacement capability of the DC motor and lead screw with the high precision and fast response of the PZT stack (Lin et al., 2016). Another example is the use of PZT bimorph actuators in combination with shape memory alloy (SMA) actuators to create a double actuator that can achieve large stroke and high force output (Zhu et al., 2020). One of the recent trends in the development of PZT actuators is the use of new materials and structures to improve their performance. For example, Ferroelectric Relaxor-PbTiO3 (FR-PTO) ceramics have been proposed as a new material for PZT actuators due to their high strain and low hysteresis (Zhang et al., 2019). The use of new structures, such as PZT nanowires and PZT thin films, has also been investigated to improve the performance of PZT actuators in MEMS applications (Wang et al., 2019; Lu et al., 2020).

## 3. Modelling

The proposed double actuator model consisting of a DC motor plus lead screw in series with a piezoelectric stack has potential applications in various fields, including antenna pointing control when tracking a satellite. The requirements for antenna pointing control involve large amplitude motion with time constants measured in a few seconds for moving between satellites, as well as fine control for tracking a given non-geostationary satellite. The combination of the large displacement capability of the DC motor and lead screw with the high precision and fast response of the PZT stack makes it suitable for this application. The performance of the double actuator model has been tested by setting the step input to 0.05mm for fine control and 10mm for larger input. The initial motion is provided by the piezoelectric stack, and this is then washed out as the DC Motor rotor angle moves to the new operating point. The model will be used to obtain the frequency response of the system, A Bode plot can be generated using the Simulink® Control Design™ tool to understand the overall actuator performance. The initial state on the current controller integrator has been set to a small non-zero number to avoid linearizing the Abs block around zero, and the PZT stack can be disabled to generate a Bode plot for the DC Motor by itself.

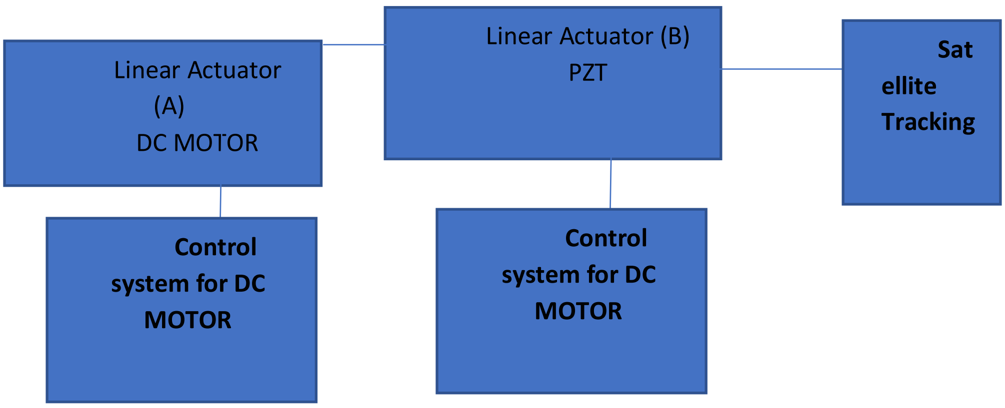


**Figure 1: Block diagram for the proposed System**

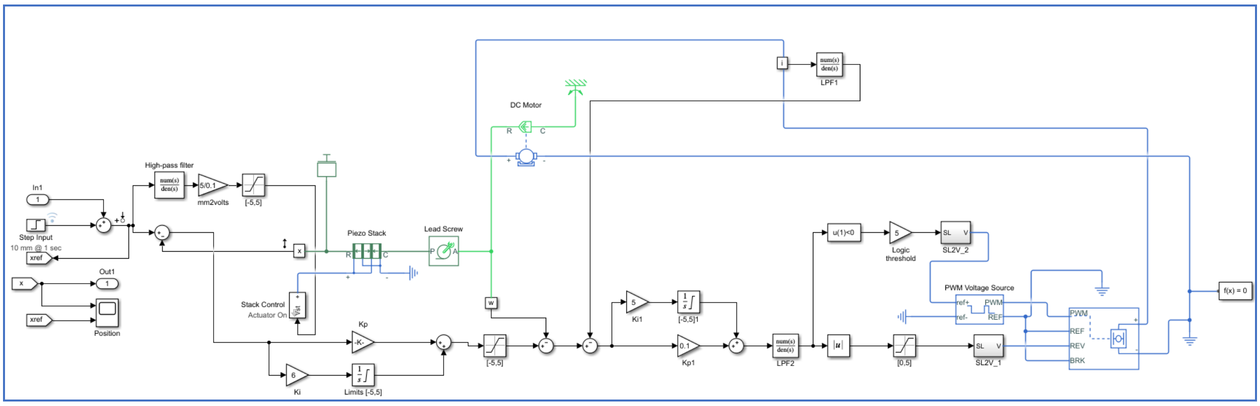


**Figure 2: Block diagram for the proposed System**

The parameters of the two linear actuators are shown in Figure (3). Where the two actuators were connected using lead screw , and the output of the piezo stack is connected to position sensor as shown in figure (5) , the output is the displacement from the piezo stack.

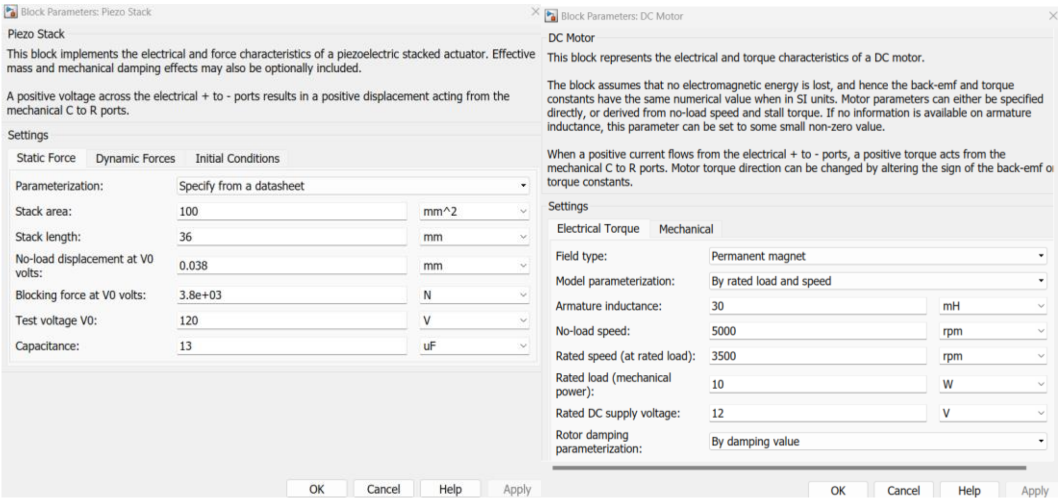


**Figure 3: specifications for the PZT and DC MOTOR**

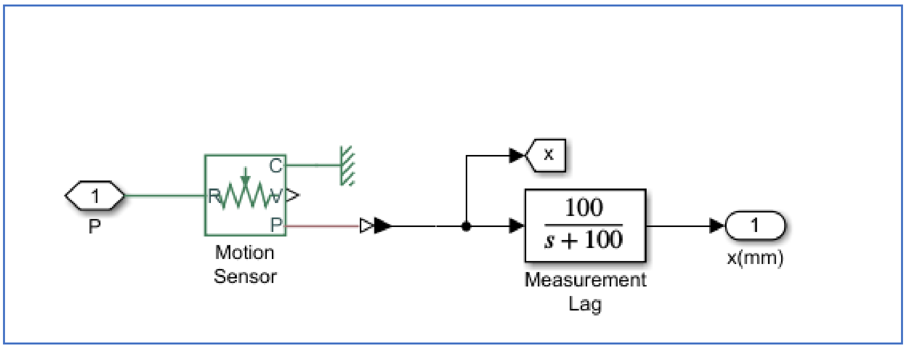


**Figure 4. Block diagram for the proposed mass sensor (x)**

The position sensing is obtained by high pass filter with gain 5/0.1 for saturation limit -5 to +5, and transfer function s/1+s, also the parameters for the gains (KP and KI ) were taken as 1.75 and 6 respectively. The piezo stack is enabled, then normalised based on voltage using 1/5 gain , then the voltage is maximised to stack voltage 320 V using a gain block. Additionally, the voltage controller is used( controlled voltage source ) . On the other hand the voltage control and drive circuit for the DC motor is shown in figure (5). Regarding the modelling of sensing position ( this sensor was presented in figure 2 as w after the leadscrew ) it can be presented in figure (6).

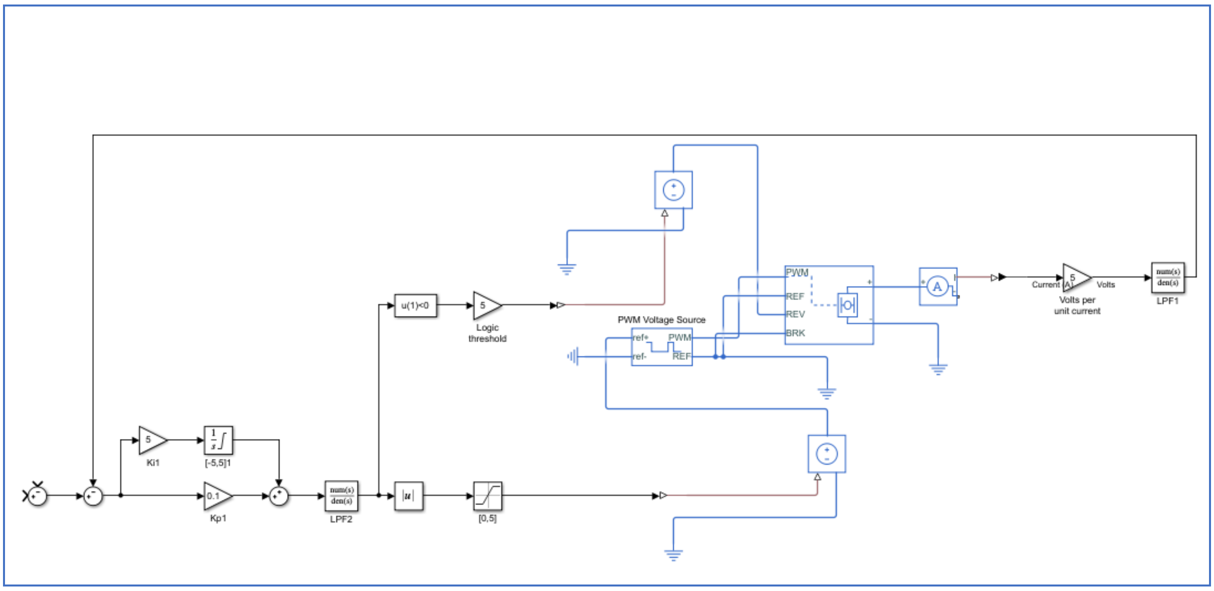


**Figure 5: The drive circuit and voltage control for the DC-motor**

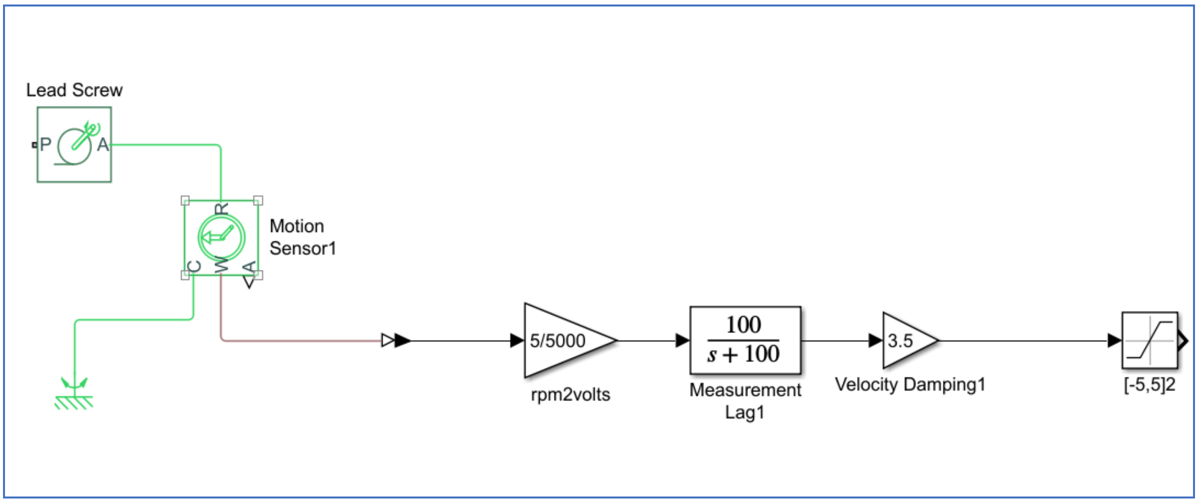


**Figure 6: The position sensing for leadscrew**

## 4. System Results

The plot shows the extension of the double actuator as the control system tracks a reference input. The step input of 50mm represents a large input, and the plot demonstrates the ability of the DC motor and lead screw combination to support large displacements, while the PZT stack provides fast and precise control to track the reference demand. The PZT stack initially provides the motion, and then the DC motor and lead screw combination wash out the initial motion and move to the new operating point. This demonstrates the effective combination of the two actuator technologies to create a large stroke actuator with highly precise positioning. The control system uses the two technologies together to achieve the desired tracking performance, with the PZT stack providing fast response and the DC motor and lead screw combination providing the necessary displacement range. Overall, the plot provides a visual representation of the capabilities and performance of the double actuator model in tracking reference signals for various input sizes.

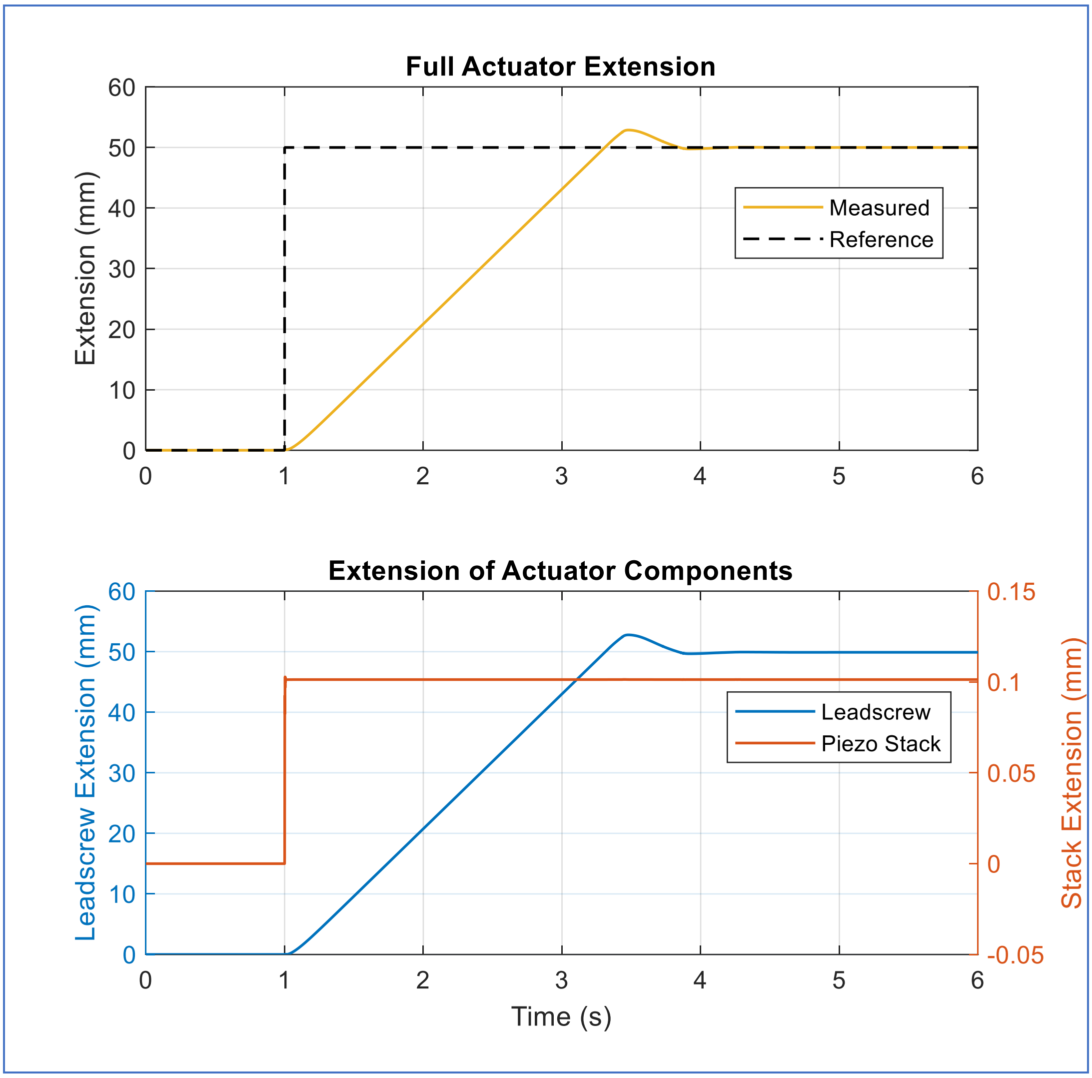


**Figure 6: The position analysis for the piezo electric stack .**

The double actuator model presented in this study offers several advantages over conventional actuation systems. For instance, the use of a PZT stack allows for high precision and fast response, while the DC motor and lead screw combination supports large displacements. Additionally, the combination of the two actuator technologies enables precise and efficient control of the actuator. This can have significant implications in various applications such as robotics, aerospace engineering, and medical devices, where precise and efficient actuation is crucial. In addition to the advantages, the double actuator model also presents some challenges. For instance, the integration of the PZT stack and the DC motor requires careful design and control of the system. Moreover, the PZT stack has a limited range of displacement, which may be a disadvantage in applications that require large stroke capabilities. Therefore, careful consideration of the application requirements is necessary when designing and implementing the double **actuator model.** To linearize the circuit and view the frequency response, the MATLAB command 'linmod' can be used. This command calculates the state-space model and linearizes it around the operating point. The linearized model can be used to analyse the frequency response of the system using MATLAB or Simulink.

In Simulink, the linearized model can be opened in the Model Linearizer by clicking on the 'Linear Analysis' tab and selecting the 'Linearize' option. Then, the 'Bode' option can be selected to obtain the Bode plot of the system's frequency response. It is important to note that the initial state on the current controller integrator should be set to a small non-zero number to avoid linearizing the Abs block around zero. Additionally, the PZT stack can be disabled to generate a Bode plot for the DC motor by itself.

Analysing the frequency response of the double actuator system can provide valuable insights into the system's behaviour, stability, and performance. By analysing the Bode plot, it is possible to identify the system's resonant frequency, gain, and phase margin, which are essential parameters for designing a robust control system. Overall, the linearization of the double actuator system can help to optimize its performance and ensure stable and efficient operation in various applications.

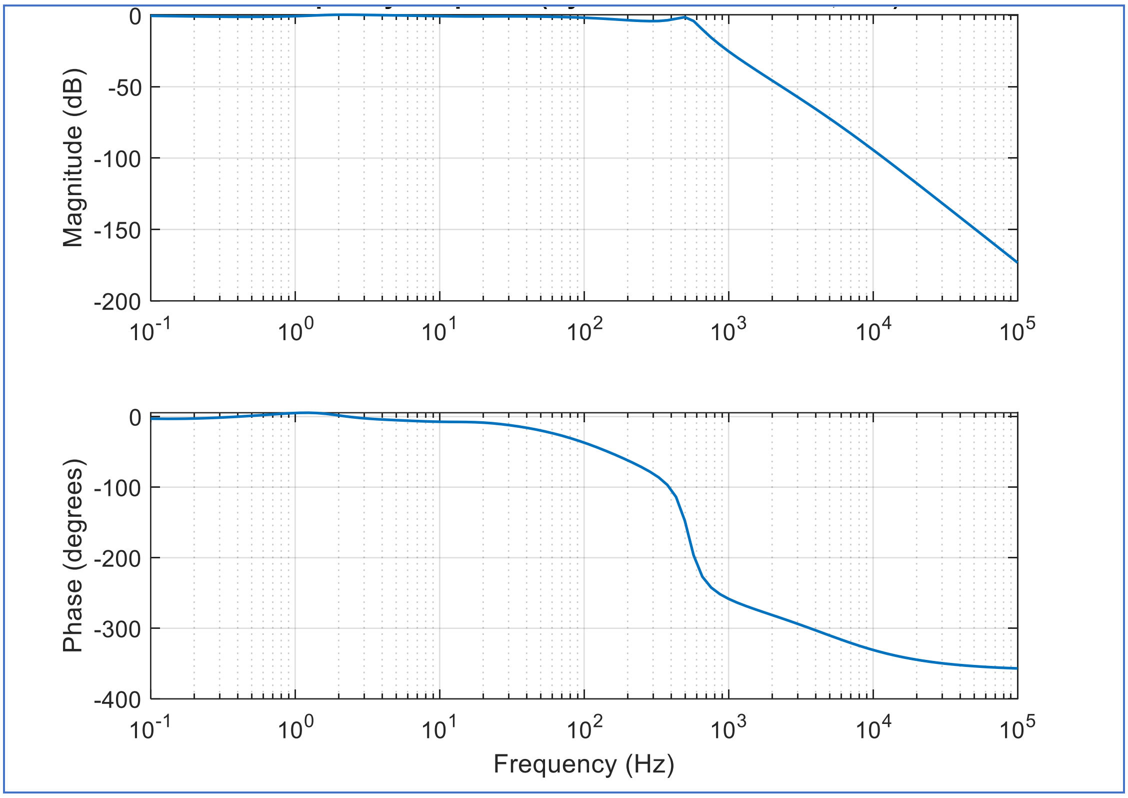


**Figure 6: The Bode diagram for the piezo electric stack .**

## 5. Conclusions

In conclusion, the double actuator model consisting of a DC motor plus lead screw in series with a PZT stack shows promising results in terms of precision, speed, and stroke capabilities. The integration of the PZT stack and the DC motor offers a unique combination of high precision and large displacement capabilities. The control system uses these technologies together to track the reference signal, allowing for efficient and precise actuation. The application of the double actuator model can have significant implications in various fields, including robotics, aerospace engineering, and medical devices, where precise and efficient actuation is crucial. The model has been demonstrated to be effective in antenna pointing control when tracking a satellite, where large amplitude motion with time constants measured in a few seconds is required to move between satellites, and fine control is required to track a given non-geostationary satellite.

Further research in this area could lead to the development of more efficient and effective actuation systems, with significant implications for various applications. The linearization of the system and analysis of its frequency response can provide valuable insights into the system's behavior, stability, and performance, and help optimize its performance for specific applications.

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