EE 3CL4: Intro. to Linear Control Systems
Appendix to Lab 1

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The following material provides a description of the motor that we will use in the experiments for EE 3CL4. This material was written by Dr. Anthony Vaz.

2. Laboratory Servomechanism

The laboratory servomechanism that you will be using in this experiment is illustrated in Figure 1. The servomechanism consists of two components: a Servomechanism Electronics Unit and Servomotor Unit. The Servomechanism Electronics Unit consists of a power amplifer and encoder processing electronics. A detailed view of the Servomechanism Electronics Unit is shown in Figure 2. The Servomotor Unit consists of a DC motor and an encoder that is used to measure the angle of the motor shaft. A detailed view of the Servomotor Unit is shown in Figure 3.

The Servomechanism Electronics Unit has 14 LED's. The yellow LED indicates whether the unit is powered on or off. The 12 green LED's give a binary representation of the motor's shaft angle. They display a binary number between 0 and 2399. The red LED flashes until the encoder has been calibrated. After calibration, the red LED turns off. The encoder is calibrated by rotating the motor shaft through the 0 degree position.

The Servomechanism Electronics Unit has three switches. The power switch is located on the left hand side of the box. The motor inhibit switch is located on the left hand side of top of the box. The motor switch controls whether the motor drive voltage is either *enabled* or *inhibited*. During power up and power down, the motor inhibit switch should be set to *inhibit*; otherwise, an erratic transient motor drive voltage will be applied to the motor. The resolution switch determines the resolution used to measure the motor shaft angle. With *1REV* resolution, motor angles from 0 degrees to 360 degrees are represented by a binary count from 0 to 2399. With *2 REV* resolution, motor angles from 0 degrees to 720 degrees are represented by a binary count from 0 to 2399.

The Electronics Unit has 6 banana plugs. The red +12V, black GND, and green -12V banana are used to provide power for the electronic circuits that are constructed on the breadboard. The purple angle output banana plug provides an analog voltage that is proportional to the binary number used to represent the motor shaft angle. A binary count of 0 corresponds to -10V and a binary count of 2399 corresponds to +10V. The orange rate output banana plug provides an analog voltage that is proportional to the rate of rotation of the motor shaft. When the motor rotates at full speed in the clockwise direction an analog voltage of +6V is produced. When the motor rotates at full speed in the counter-clockwise direction an analog voltage of -6V is produced. The brown command input banana plug is used to give rate commands to the motor. A rate command voltage of +12V causes the motor shaft to rotate at full speed in the clockwise direction; 0 V causes the motor shaft to remain stationary; and -12V causes the motor shaft to rotate at full speed in the counterclockwise direction. Rate command voltage should not exceed 12V; otherwise, damage will ensue.

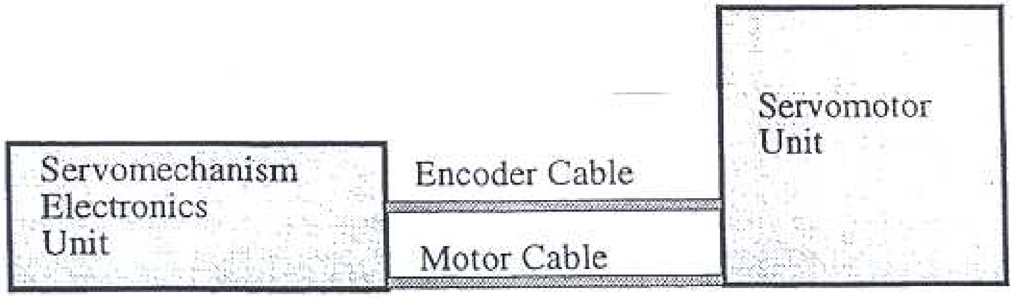

Figure 1: Overview of Laboratory Servomechanism

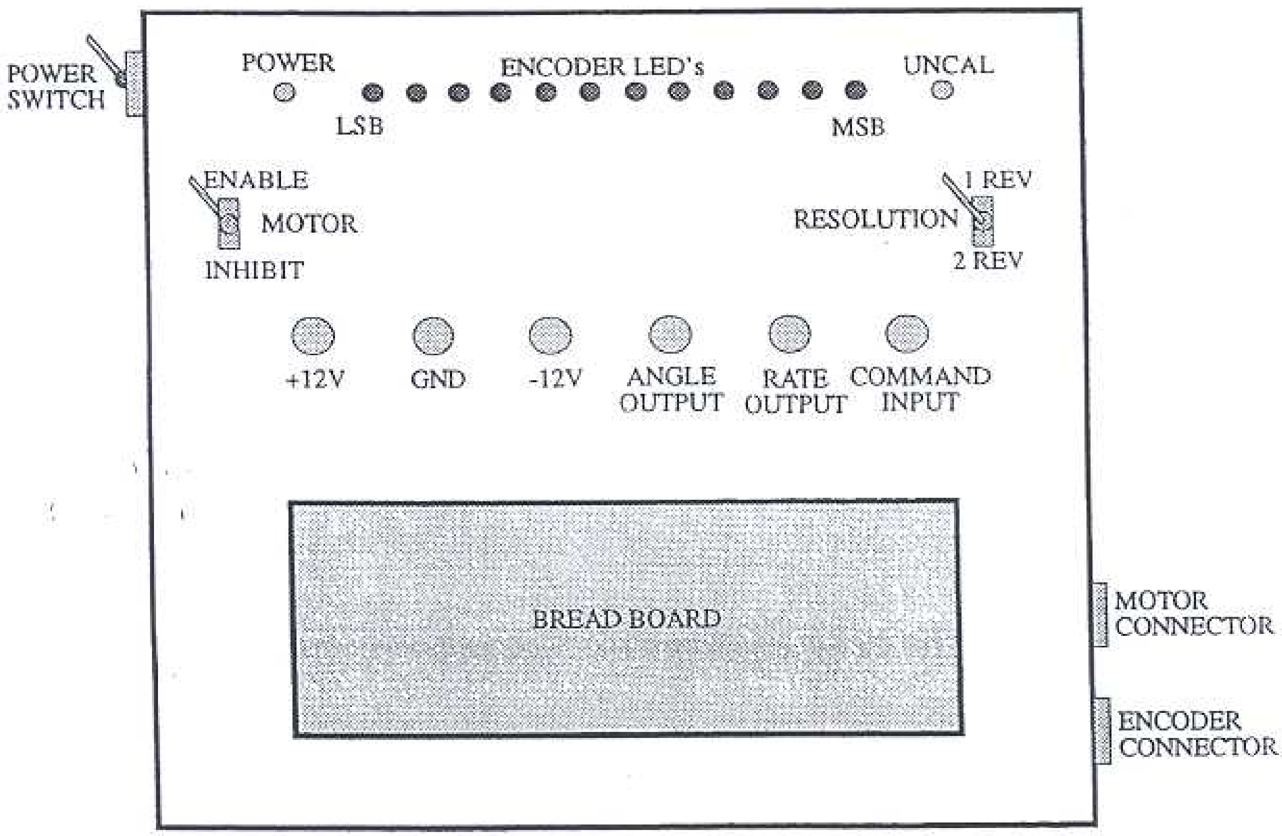

Figure 2: Detailed View of Servomechanism Electronics Unit

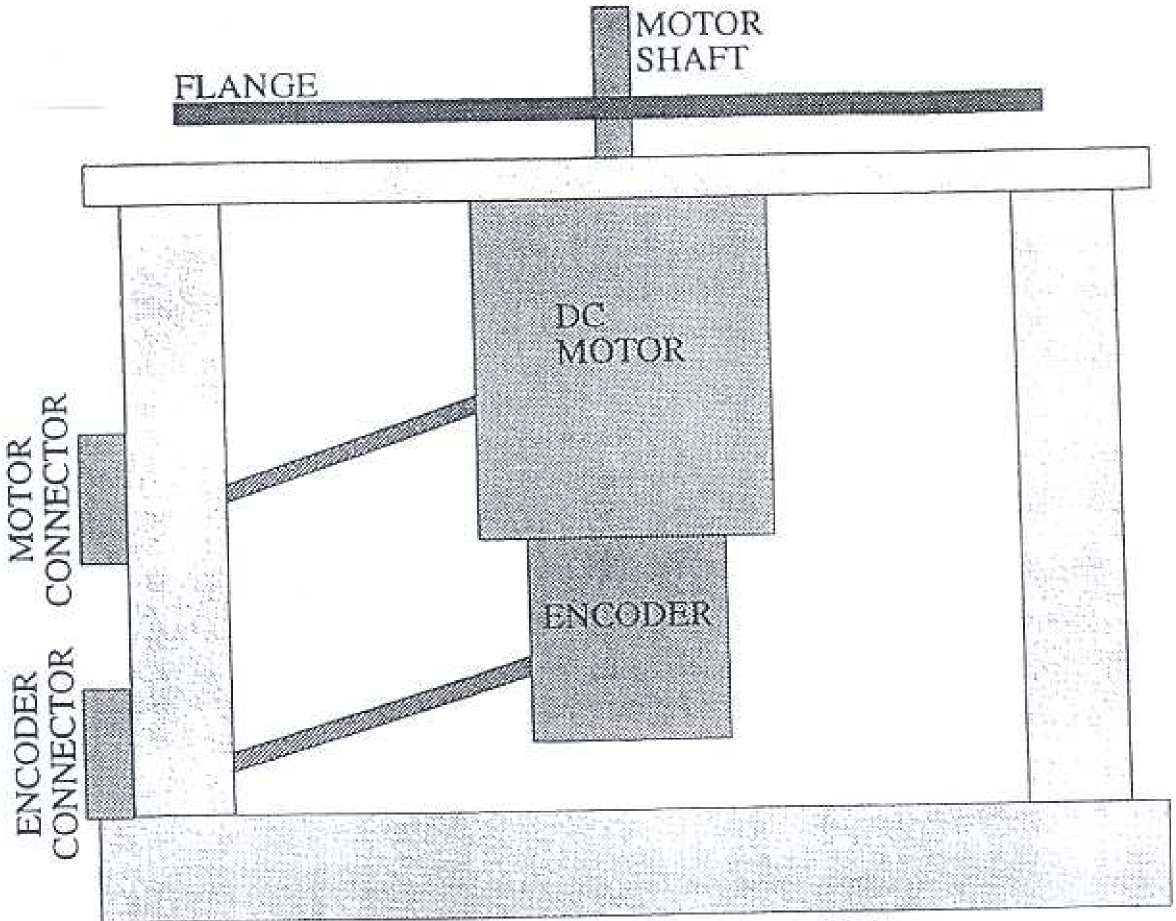

Figure 3: Detailed View of Servomotor Unit

2.1. Nominal Block Diagram of Servomechanism Operation

The conceptual block diagram of the servomechanism in the Laplace Transform domain is illustrated in Figure 4. The command input voltage $U(s)$ causes the motor shaft to rotate at a velocity $\Omega_m(s)$. Integrating the motor shaft velocity yields the angle of the motor shaft $\Theta_m(s)$. The motor shaft velocity $\Omega_m(s)$ can be monitored in terms of a voltage $\Omega(s) = K_\omega \cdot \Omega_m(s)$. The motor shaft angle can also be monitored in terms of a voltage $\Theta(s) = K_\theta \cdot \Theta_m(s)$. The units that correspond to these signals are indicated within the square brackets in Figure 4. Note $K_\Omega \neq K_\theta$; hence, the rate output $\Omega(s)$ is proportional (but not equal) to the slope of the angle output $\Theta(s)$.

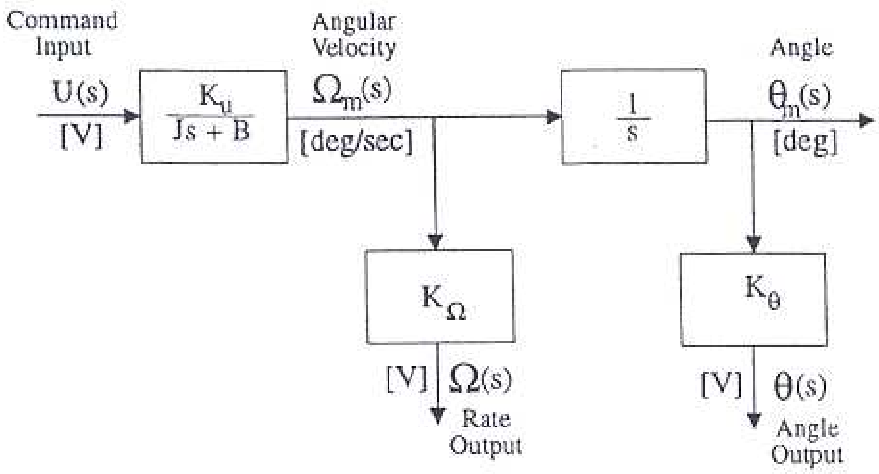

Figure 4: Pulse Width Modulated Motor Drive Voltage

The transfer function between the input $U(s)$ and the output $\Theta(s)$ is given by the following:

$$\frac{\Theta(s)}{U(s)} = \frac{K_u K_\theta}{s(Js + B)}.$$

This can be put into the canonical form for a second order servomechanism with the substitutions $A = \frac{K_u K_\theta}{B}$ and $\tau_m = \frac{J}{B}$ to yield

$$G(s) = \frac{\Theta(s)}{U(s)} = \frac{A}{s(s\tau_m + 1)}.$$

In this experiment, the techniques for estimating the parameters A and τ_m will be studied.

The parameters and signals corresponding to the block diagram in Figure 4 and the above the transfer functions have the units listed in the following table.

Quantitiy	Units
$\theta_m(t)$	deg
$\theta(t)$	V
$\Omega_m(t)$	deg/ sec
$\Omega(t)$	V
J	$N \cdot m \cdot \sec^2$
B	$N \cdot m \cdot \sec$
K_u	$\deg \cdot N \cdot m / V$
K_Ω	$V \cdot \sec / \deg$
K_θ	$V / \deg$
$A = \dfrac{K_u K_\theta}{B}$	$1 / \sec$
$\tau_m = \dfrac{J}{B}$	sec

2.2. Principles of Servomechanism Electronics Unit Operation (Optional)

A detailed understanding of Servomechanism Electronics Unit and Servomotor Unit is not required for this experiment. The information in the following subsections is provided for the curious student.

The electronics unit consists of a DC power supply and two circuit cards. One circuit card is used to produce a pulse width modulated square voltage signal that is used to drive the DC motor. The other circuit card is used to process the signals from the encoder that measures the angle of the motor shaft.

2.2.1. Pulse Width Modulation of Motor Drive Signals (Optional)

The power amplifer unit produces a pulse width modulated square voltage signal that is used to drive the DC motor in the servomotor unit. The square wave has a peak amplitude of 14V and a frequency of 18kHz. This causes the high pitched whine that is barely audible when the Servomechanism Electronics Unit is powered on. The duty cycle of the square wave is controlled by the command input. This is illustrated in Figure 5.

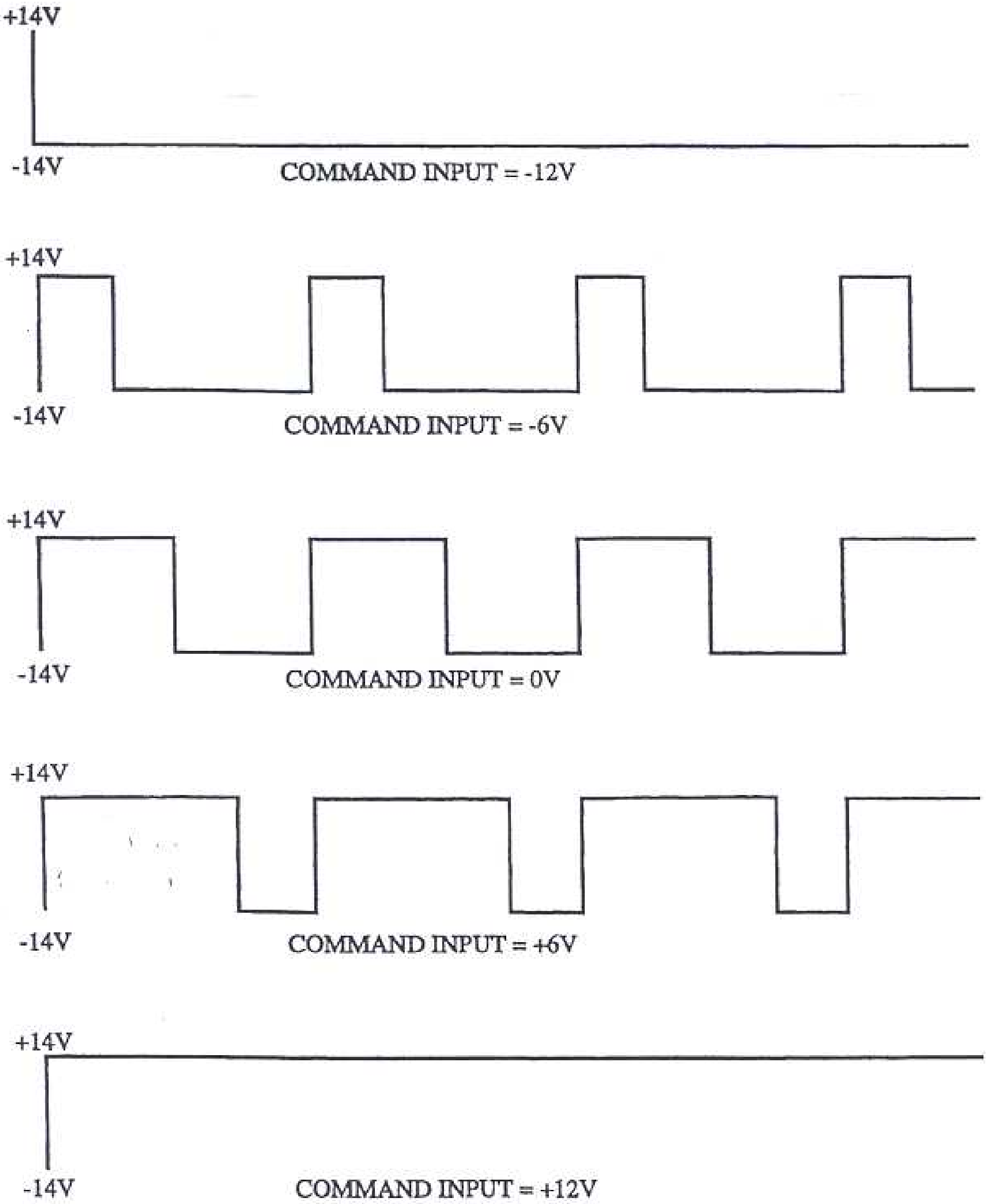

Figure 5: Pulse Width Modulated Motor Drive Voltage

2.2.2. Encoder Operation (Optional)

An encoder is a device for measuring the angle of a shaft. They are commonly used in robotic manipulators to measure joint angles[1]. The Servomotor Unit uses an incremental encoder. The encoder consists of a disk with radial lines that is rotated by the encoder shaft. The disk is made of transparent material with opaque thin lines. The encoder body supports an LED light source that illuminates one side of the encoder disk and three photodetectors (**A**, **B**, and **Z**)[2] used to sense light on the other side. When a line of the disk is positioned below a photodetector, the light to the photodetector is interrupted . The radial disk is illustrated in Figure 6. The resolution of the encoder is defined as the number of lines in the encoder disk. Accordingly, an encoder with N lines has an angular resolution of $360°/N$. The encoder in the servomotor has a disk with 600 lines, which gives an angular resolution of 0.6°. However, it is possible to increase this resolution electronically. This will be explained after we discuss how positional information can be infered from the encoder.

As the disk rotates, each detector produces a voltage waveform that resembles a pulse train of sinusoid peaks. These pulse trains are converted to TTL logic signals through the use of comparators. The period of the TTL square waves is a function of the rotation speed. The **A** and **B** photodetectors are positioned so that **A** is positioned above the middle of an encoder line when **B** is at the edge of an encoder line. Accordingly as the encoder disk rotates, TTL square wave of **A** is phase shifted by 90° from TTL square wave of **B**. For clockwise rotations **A** leads **B**, whereas for counterclockwise rotations **B** leads **A**. This illustrated in Figure 7(a) and 7(b). The rising and falling edges of the square waves can be used to infer the direction of rotation. Furthermore, there are 4 edge transitions that correspond to each rotation $360°/N$. Hence by detecting the edges of the square waves, the angular resolution can be increased to $90°/N$.

The **Z** photodector is positioned so that it exclusively detects the 0° line of the encoder. A comparator is used convert the voltage pulse from Z into a TTL pulse. Accordingly, the **Z** pulse can be used to detect when the encoder shaft is at 0°. The width of the pulse is dependent upon the dwell of the shaft at the 0° position.

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[1] For a detailed discussion of encoders construction and use, consult the following book:
R.D. Klafter, T. Chmielewski, M. Negin, *Robotic Engineering: An Integrated Approach*, Prentice Hall, Englewood Cliffs, New Jersey, 1989, pp. 342-355.

[2]The explaination given is a simplication to explain the conceptual operation of the encoder. In an actual encoder, each line alignment is detected by a pair of photodetectors and a comparator to minimize the effects of variations in light intensity that result from varing rotation rates. A reticle is placed in front of each photodetector to improve alignment accuracy.

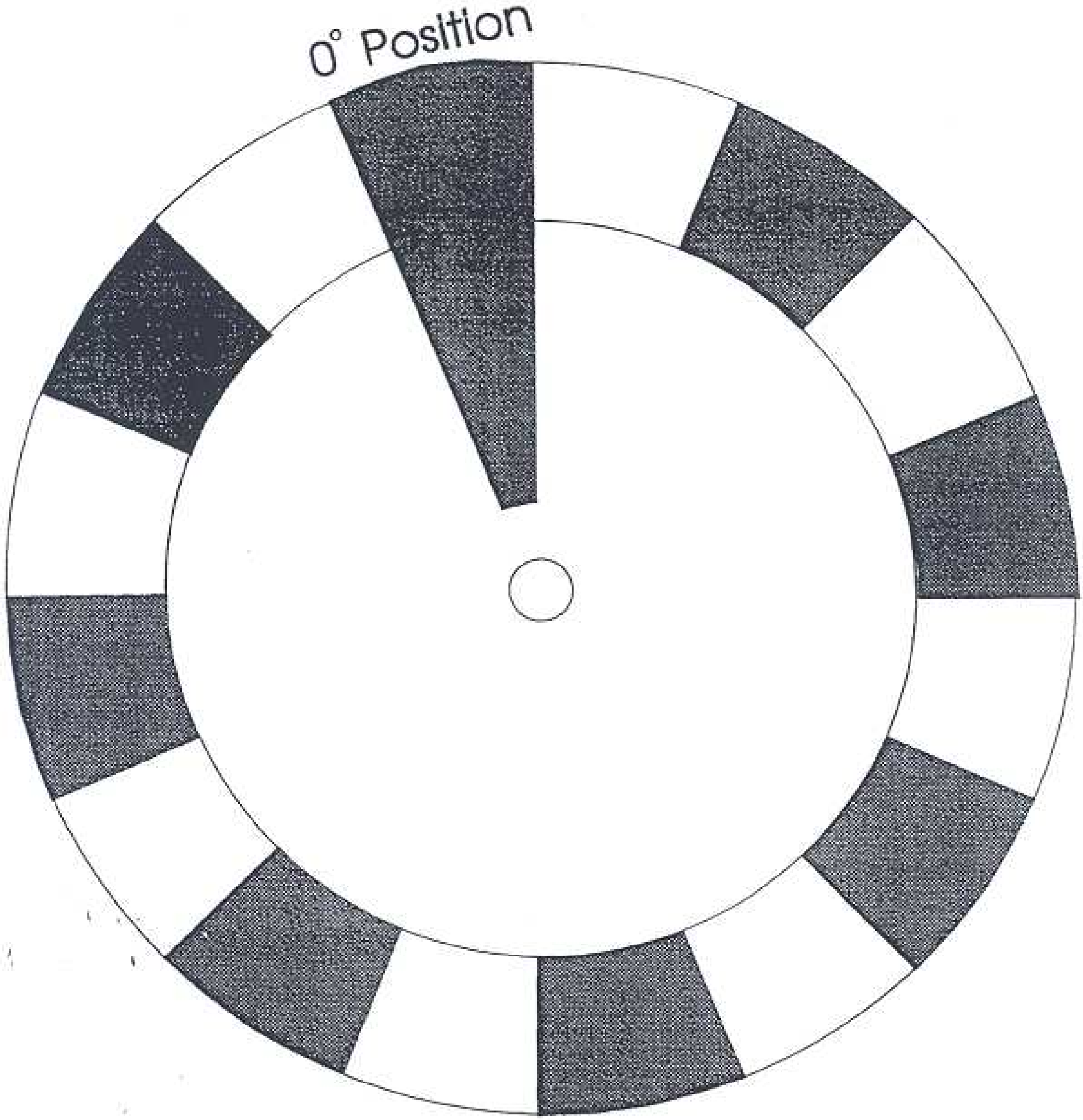

Figure 6: Incremental Encoder Disk with 8 Lines

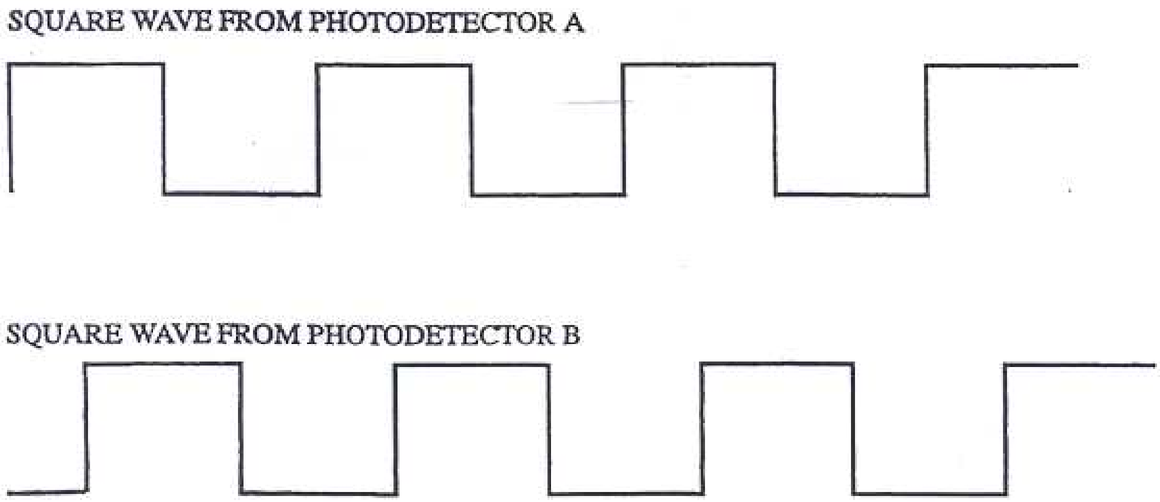

Figure 7a: TTL Square Waves of A and B (Clockwise Rotation)

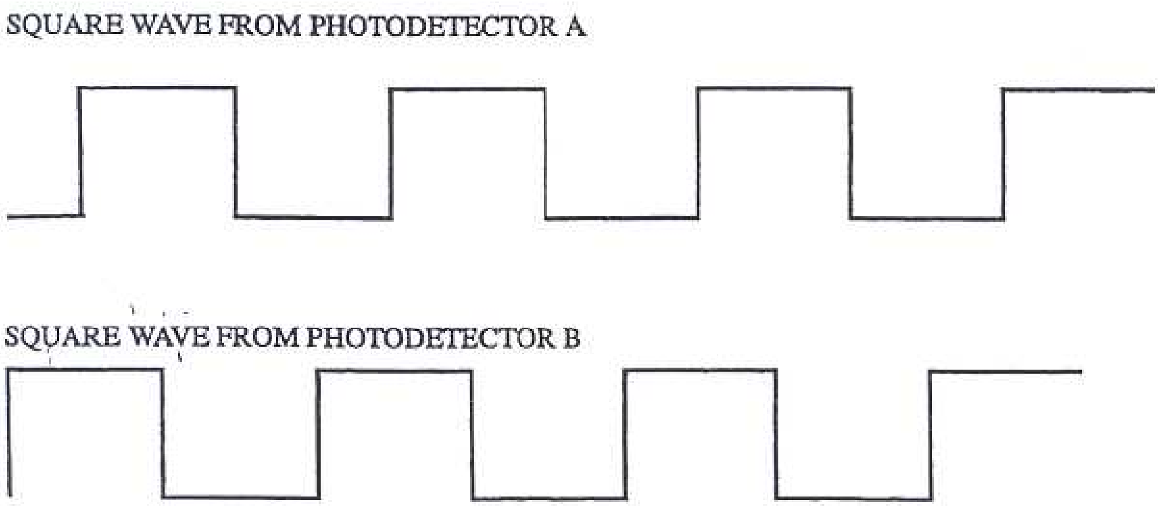

Figure 7b: TTL Square Waves of A and B (Counterclockwise Rotation)

The Servomechanism Electronic Unit contains a circuit card for powering the encoder and processing the A, B, and Z encoder signals. The edges of the A and B square waves are used to increment a counter when A leads B, and decrement it when B leads A. The value of the 12 bit counter is displayed on the green LEDS. The Z pulse is used to reset the counter upon power up. A digital to analog converter is used to produce the angle output voltage that corresponds to the counter value. A frequency to voltage converter is used to produce the rate output voltage that corresponds to the A square wave; a multiplexer and level shifting circuitry is used to provide the correct polarity.