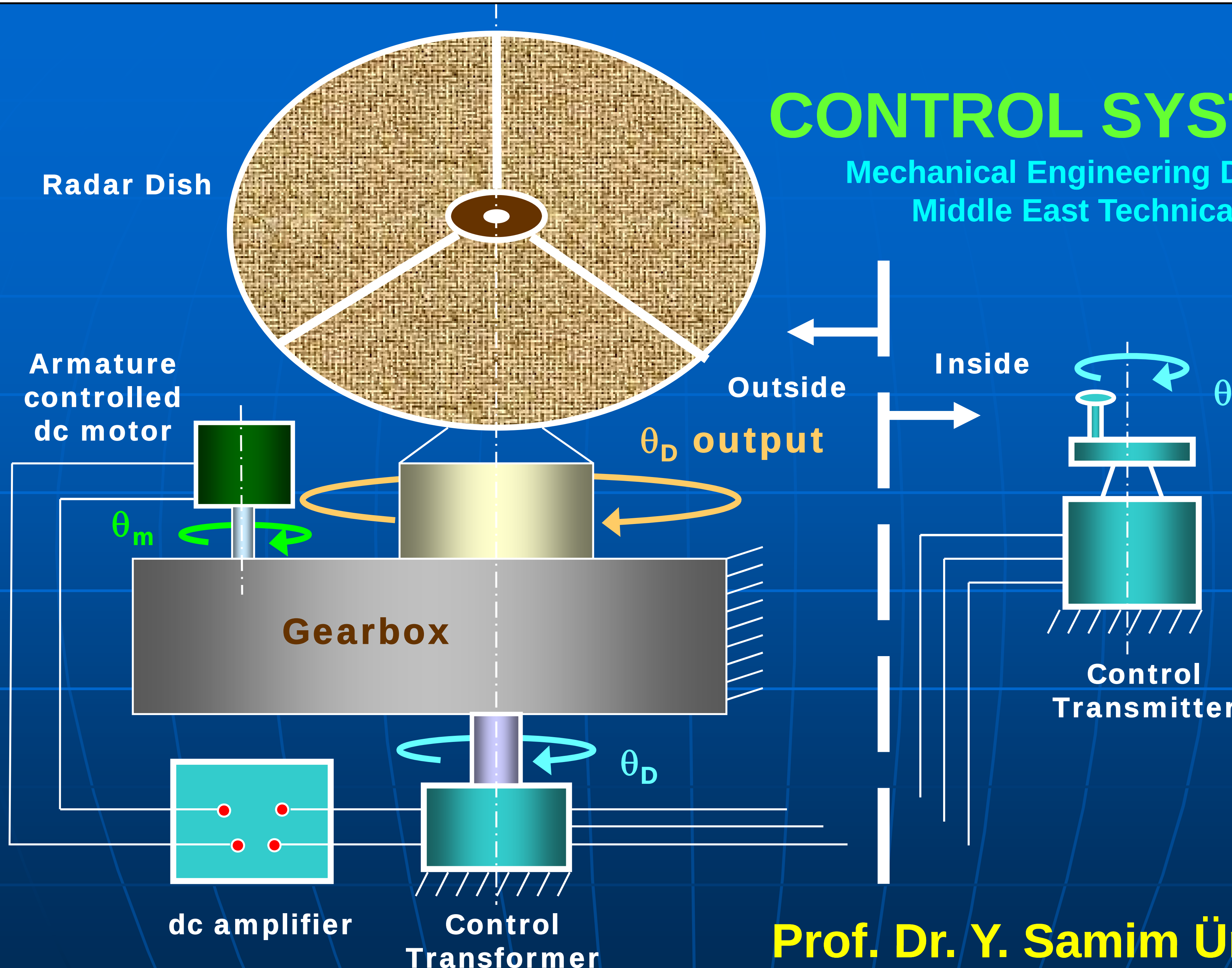
# ME 304
# CONTROL SYSTEMS

Mechanical Engineering Department,
Middle East Technical University

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CH VII

## COURSE OUTLINE

I. INTRODUCTION & BASIC CONCEPTS
II. MODELING DYNAMIC SYSTEMS
III. CONTROL SYSTEM COMPONENTS
IV. STABILITY
V. TRANSIENT RESPONSE
VI. STEADY STATE RESPONSE
**VII. DISTURBANCE REJECTION**
VIII. CONTROL ACTIONS & CONTROLLERS
IX. FREQUENCY RESPONSE ANALYSIS
X. SENSITIVITY ANALYSIS
XI. ROOT LOCUS ANALYSIS

# DISTURBANCE REJECTION
## OBJECTIVES

**In this chapter :**

- **General disturbance rejection characteristics of open and closed loop systems will be examined.**

# DISTURBANCE REJECTION

**Nise 7.5**

At this point an attempt is made to derive a general approach to improve the steady state response for the servo and regulator (disturbance rejection) characteristics of feedback systems.

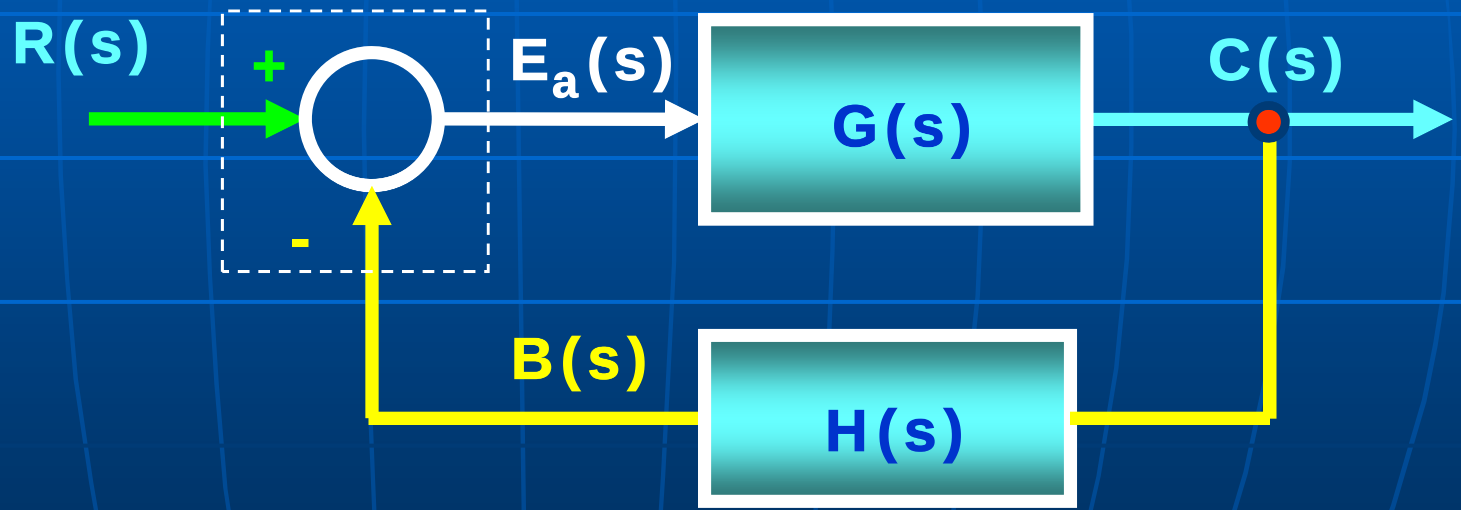
# DISTURBANCE REJECTION
## Servo Characteristics

### Servo Characteristics

- A servomechanism is a control system designed to follow a reference (command) input.
- For examining the servo characteristics of a control system; all inputs, including the plant disturbance and sensor noise, other than the reference input are assumed to be zero.

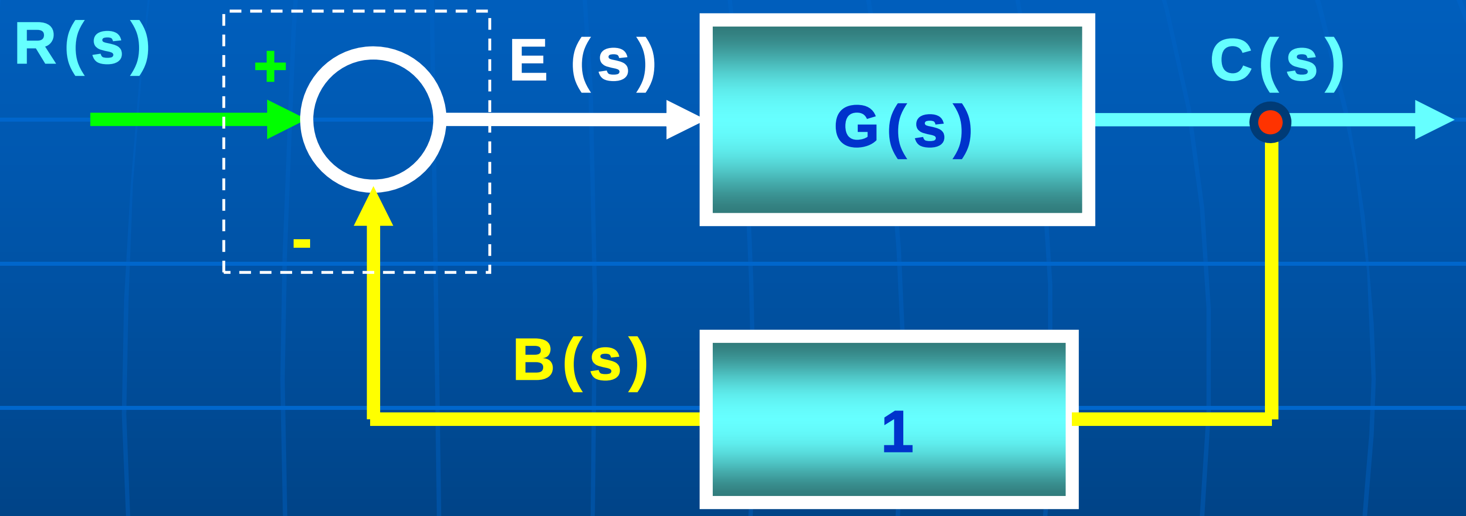
# DISTURBANCE REJECTION
## Servo Characteristics

In such a case, the block diagram of the closed loop control system reduces to the so-called **canonical** form.



# DISTURBANCE REJECTION
## Servo Characteristics

**For good servo characteristics : $E(s) = 0$**




$$E(s) = \frac{R(s)}{1 + G(s)}$$

**This can be achieved if the open loop gain K goes to infinity, i.e.**

$$|G(s)| \to \infty$$

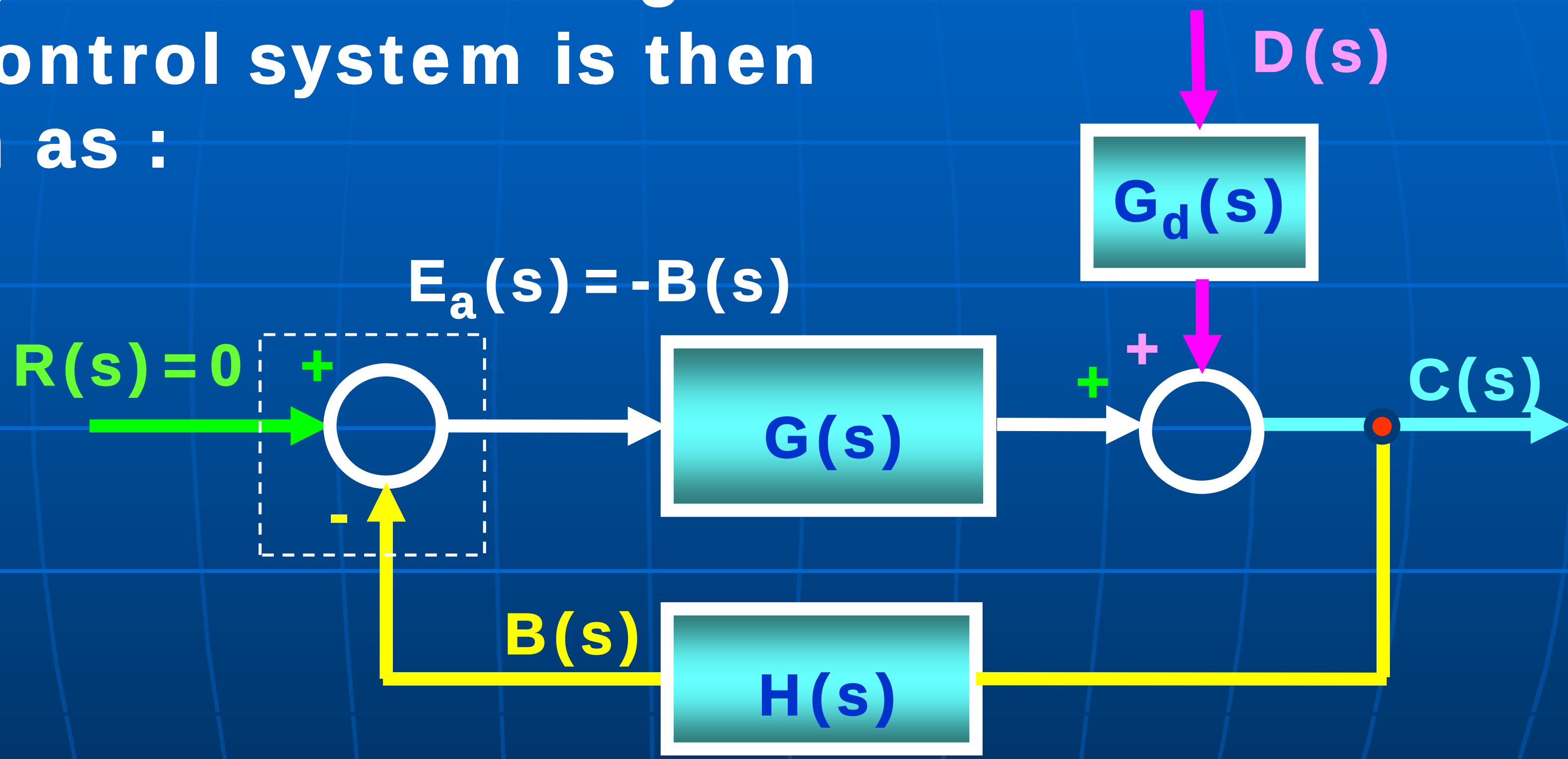
# DISTURBANCE REJECTION
## Regulator Characteristics

## Regulator Characteristics

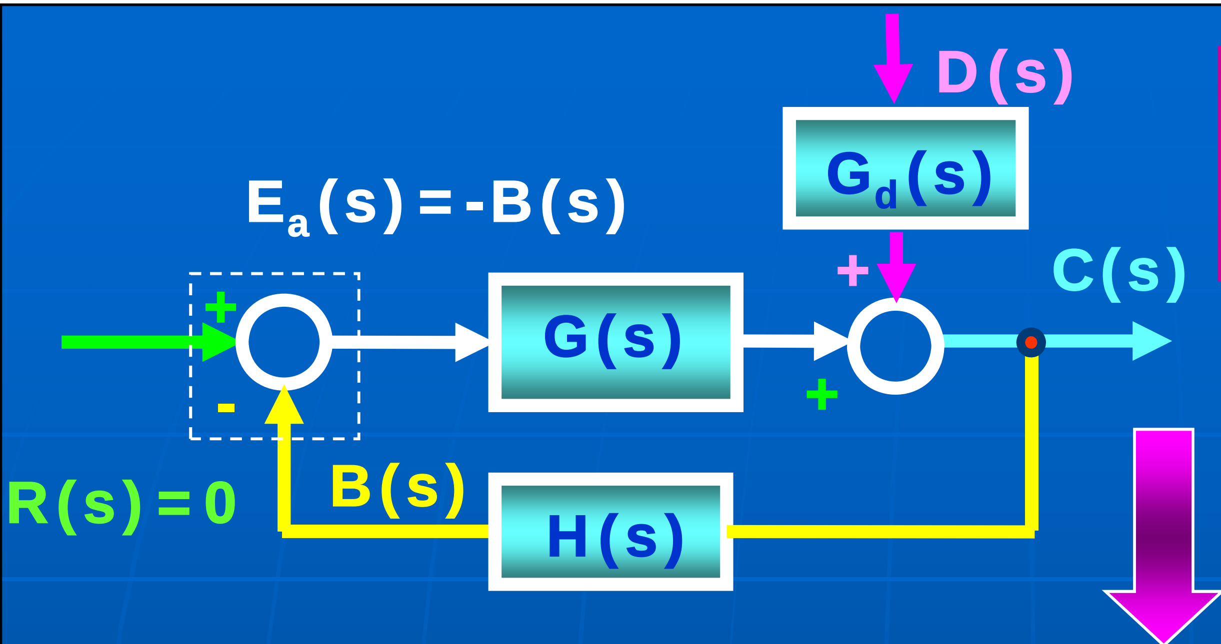
- A **regulator** is a control system designed to reject the plant disturbance when the reference input is zero.
- For examining the regulator characteristics of a control system; **all inputs, including the reference input, other than the plant disturbance input are assumed to be zero.**

# DISTURBANCE REJECTION
## Regulator Characteristics

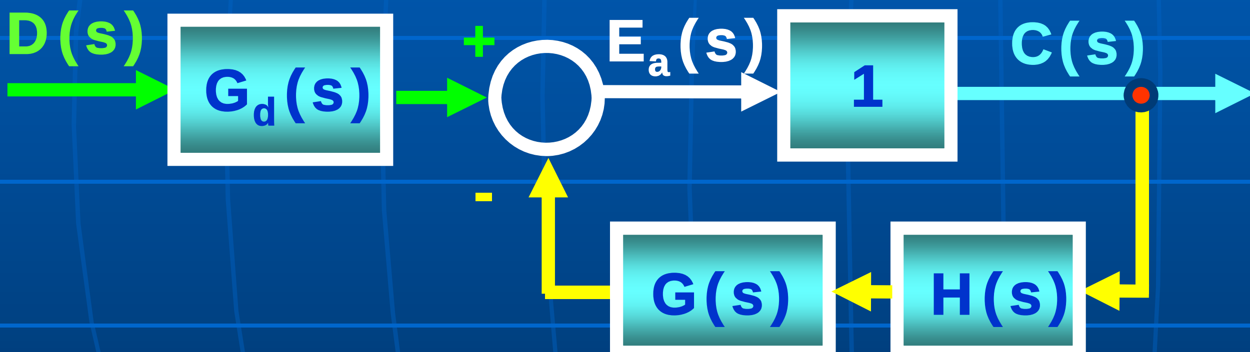
**The general block diagram of the control system is then given as :**



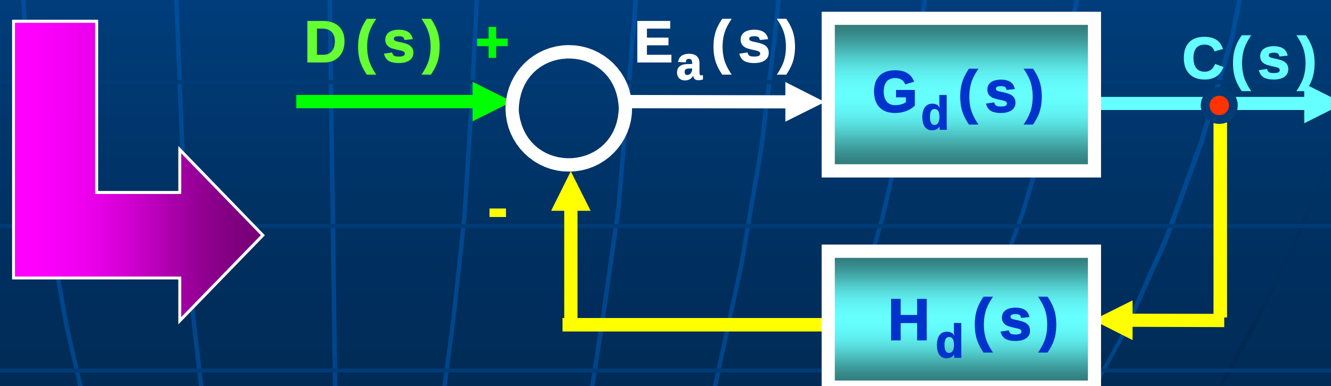
# DISTURBANCE REJECTION

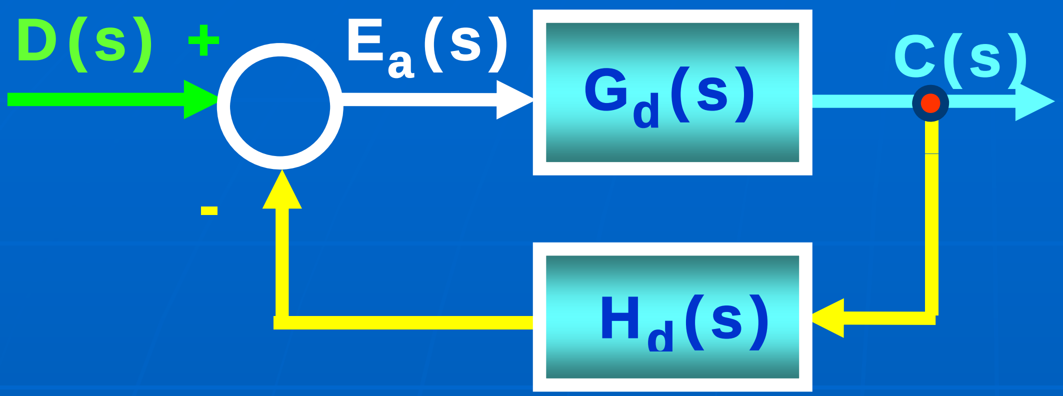



The block diagram is redrawn in the canonical form with disturbance as the input :




$$H_d(s) = \frac{G(s)H(s)}{G_d(s)}$$






# DISTURBANCE REJECTION

## Regulator Characteristics

The output due to disturbance input is given by :

$$C(s) = \frac{G_d(s)}{1 + G_d(s)H_d(s)} D(s)$$

The open loop transfer function is the same as that of the servomechanism.

$$G_d(s)H_d(s) = G(s)H(s)$$

Thus

$$C(s) = \frac{G_d(s)}{1 + G(s)H(s)} D(s)$$

$$C(s) = \frac{G_d(s)}{1 + G(s)H(s)} D(s)$$

# DISTURBANCE REJECTION

## Regulator Characteristics

For good regulator (disturbance rejection) characteristics, it is desired to have $C(s) = 0$ which can be achieved, once again, if the open loop gain K goes to infinity, i.e.

$$\Rightarrow \quad |G(s)H(s)| \to \infty$$

# DISTURBANCE REJECTION

## Regulator Characteristics

**Good servo and regulator (disturbance rejection) characteristics can be achieved, theoretically, when the open loop gain K goes to infinity, so that**

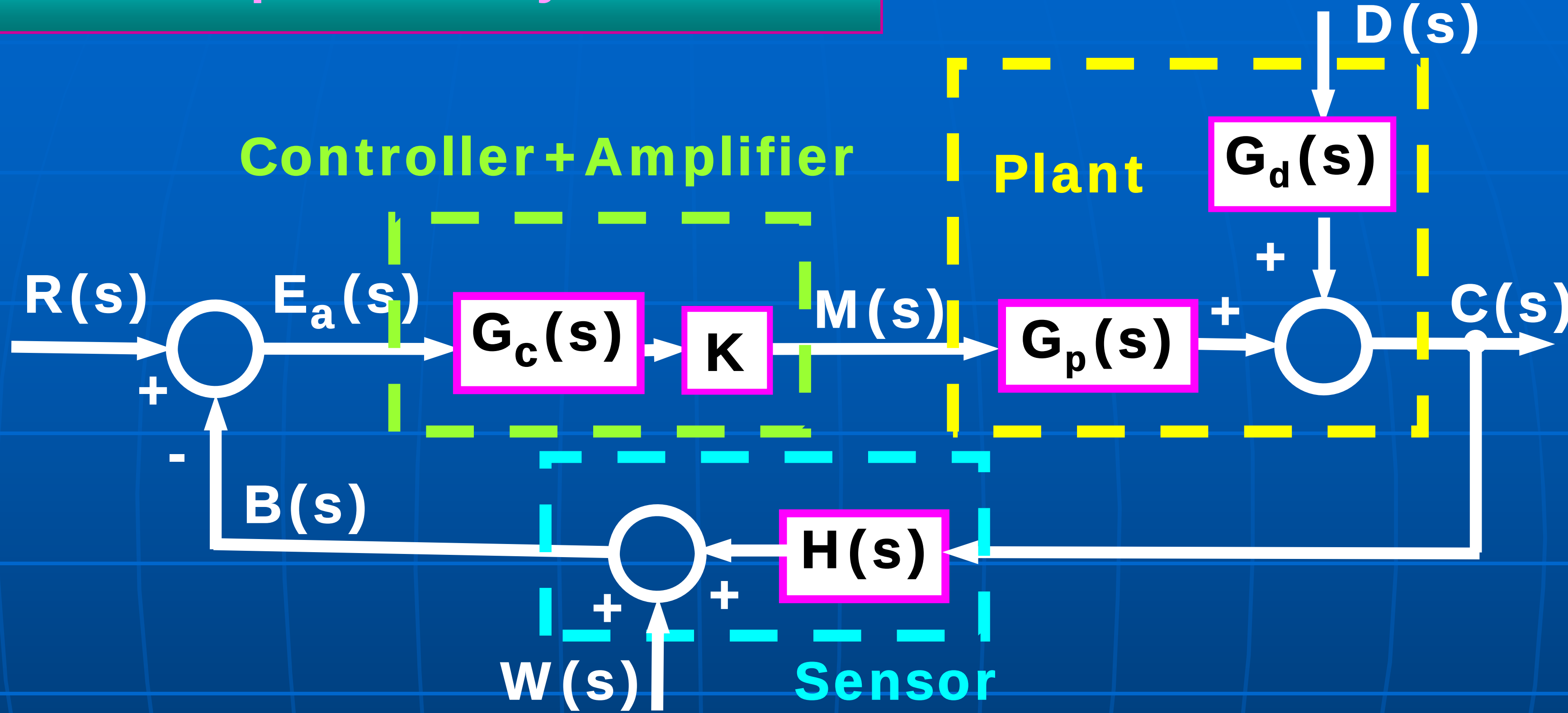
$$\left|G(s)H(s)\right| \to \infty$$

**It is important, however, to note that a large value of K may cause instability.**

**Thus, a rule of thumb is to select the largest value for the open loop gain which would not make the system unstable.**

# DISTURBANCE REJECTION

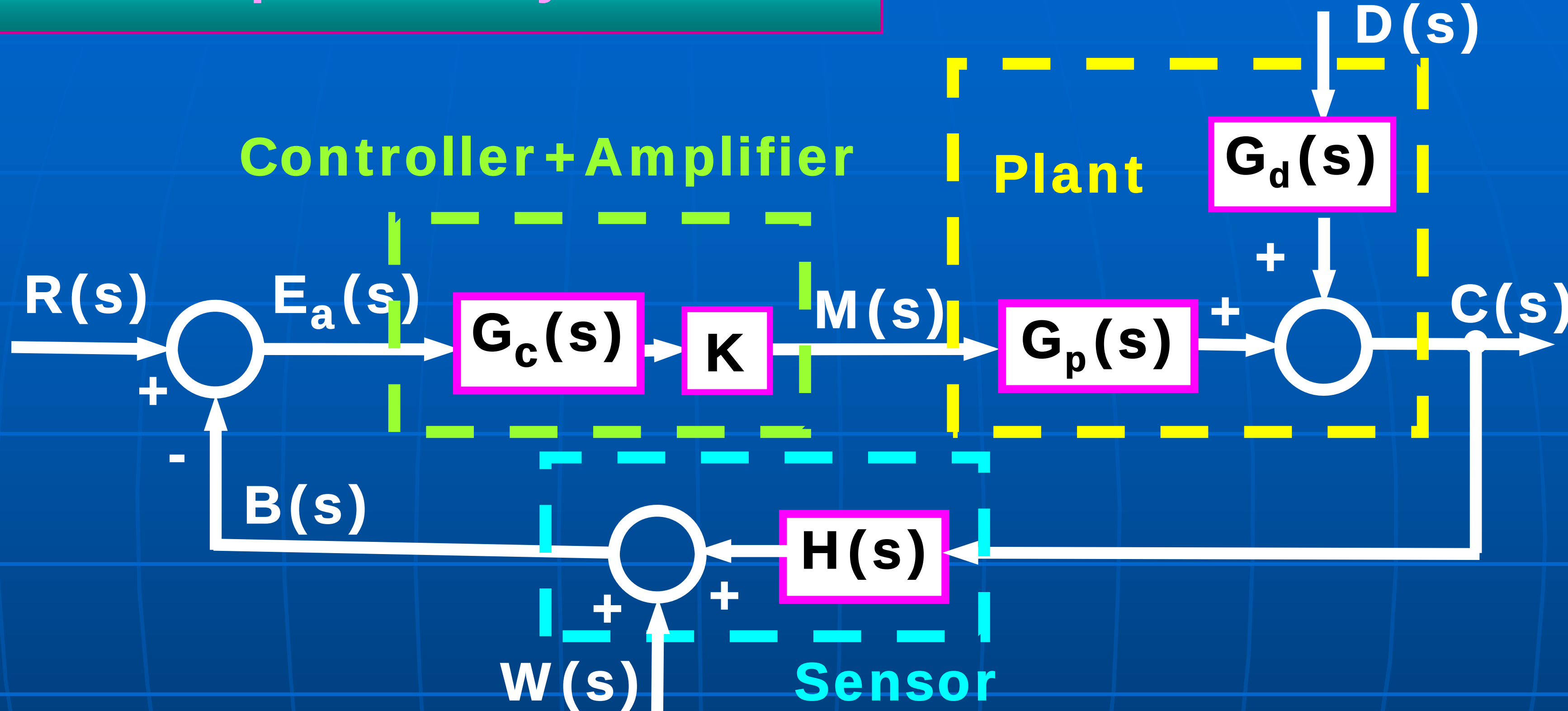
## Closed Loop Control Systems




- **D(s) : Plant disturbance**
- **W(s) : Sensor noise**

# DISTURBANCE REJECTION

## Closed Loop Control Systems




$$C = \left(\frac{KG_cG_p}{1+KG_cG_pH}\right)R + \left(\frac{G_d}{1+KG_cG_pH}\right)D + \left(\frac{-KG_cG_p}{1+KG_cG_pH}\right)W$$

**Reference Input** — **Disturbance** — **Sensor Noise**

# DISTURBANCE REJECTION

## Closed Loop Control Systems

$$C = \left(\frac{KG_cG_p}{1+KG_cG_pH}\right)R + \left(\frac{G_d}{1+KG_cG_pH}\right)D + \left(\frac{-KG_cG_p}{1+KG_cG_pH}\right)W$$

The objective is to have : $C(s) = R(s)$

As $K \to \infty$ :

$$C(s) \to \left[\frac{1}{H(s)}\right]R(s) + (0)D(s) + \left[\frac{-1}{H(s)}\right]W(s)$$

# DISTURBANCE REJECTION

## Closed Loop Control Systems

As $K \to \infty$ :

$$C(s) \to \left[\frac{1}{H(s)}\right] R(s) + (0) D(s) + \left[\frac{-1}{H(s)}\right] W(s)$$

It is clear that the effects of the disturbance can be rejected by choosing a large value for K.

However, K cannot be too large as this will lead to instability. Thus perfect rejection cannot be realized in real life applications.

# DISTURBANCE REJECTION

## Closed Loop Control Systems

As $K \to \infty$:

$$C(s) \to \frac{1}{H(s)} R(s) + \frac{-1}{H(s)} W(s)$$

For an ideal sensor :

$$H(s) = 1 \text{ and } W(s) = 0$$

Thus :

As $K \to \infty$ and with an ideal sensor :

$$C(s) \to R(s)$$

# DISTURBANCE REJECTION

## Closed Loop Control Systems

**As $K \to \infty$ and with an ideal sensor :**

**$C(s) \to R(s)$**

However, sensors having these ideal characteristics do not exist. Therefore, such perfect results can never be obtained in actual applications.

# DISTURBANCE REJECTION

## Closed Loop Control Systems

**By selecting as large a value of K as possible :**

- **The effects of disturbance can be minimized.**
- **Higher values of K, reduce the dependence of the output C(s) on $G_p$, $G_c$, and $G_d$.**
- **Thus, the effects of modeling inaccuracy and parameter variations are reduced.**
- **Dependence of the output C(s) on H(s), however, is emphasized.**

# DISTURBANCE REJECTION

## Closed Loop Control Systems

## Conclusions :

- To realize an approximation of ideal sensor characteristics as closely as possible, a high quality sensor is required. The quality of control is strongly affected by the quality of the sensor.
- The controller transfer function $G_c(s)$ should be determined to improve the stability and the dynamic behavior of the system. Thus it should allow the use of a higher value of K without causing instability.