Electronic Circuits

Prof. Nizamettin AYDIN
naydin@yildiz.edu.tr
http://www.yildiz.edu.tr/~naydin

Dr. Gökhan Bilgin
gokhanb@ce.yildiz.edu.tr

1

Control and feedback

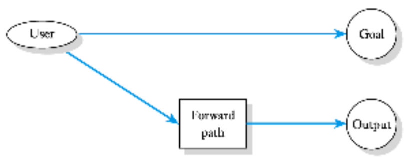
- Introduction
- Open-loop and closed-loop systems
- Automatic control systems
- Feedback systems
- Negative feedback
- The effects of negative feedback
- Negative feedback – a summary

Introduction

- **Control** is one of the basic functions performed by many systems
  – this often involves **regulation** or **command**
- Invariably, the goal is to determine the value or state of some physical quantity
  – and often to maintain it at that value, despite variations in the system or the environment

Open-loop and closed-loop systems

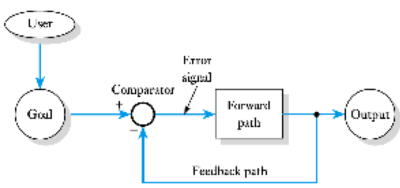
- Simple control is often **open-loop**
  – user has a **goal** and selects an input to a system to try to achieve this



(a) An open-loop system

Open-loop and closed-loop systems (contd.)

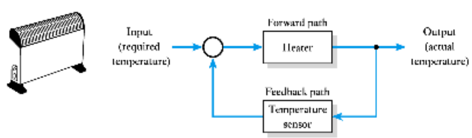
- More sophisticated arrangements are **closed-loop**
  – user inputs the goal to the system



(b) A closed-loop system

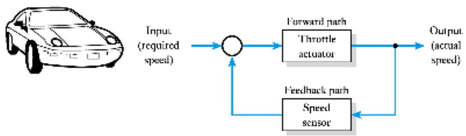
Automatic control systems

- Examples of automatic control systems:
  – **temperature control using a room heater**



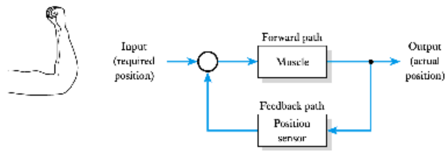
Automatic control systems (contd.)

- Examples of automatic control systems:
  - **cruise control in a car**



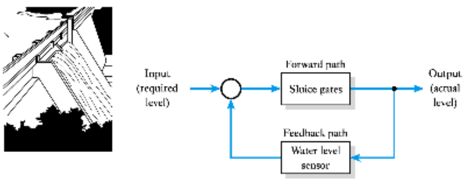
Automatic control systems (contd.)

- Examples of automatic control systems:
  - **position control in a human limb**



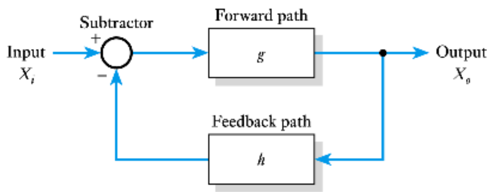
Automatic control systems (contd.)

- Examples of automatic control systems:
  - **level control in a dam**



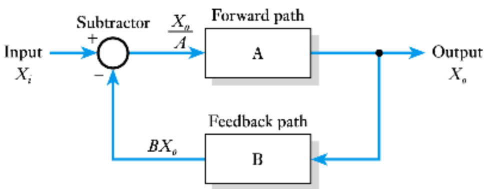
Feedback systems

- A generalised feedback system



Feedback systems (contd.)

- By inspection of diagram we can add values



$\frac{X_o}{A} = X_i - BX_o$ or rearranging $\frac{X_o}{X_i} = \frac{A}{1+AB}$

Feedback systems (contd.)

- Thus

$$\text{Overall gain } G = \frac{X_o}{X_i} = \frac{A}{1+AB}$$

- This is the **transfer function** of the arrangement
- Terminology:
  - *A* is also known as the **open-loop gain**
  - *G* is the overall or **closed-loop gain**

Feedback systems (contd.)

- Effects of the product AB
  - If AB is negative
    - If AB is negative and less than 1, $(1 + AB) < 1$
    - In this situation G > A and we have **positive feedback**
  - If AB is positive
    - If AB is positive then $(1 + AB) > 1$
    - In this situation G < A and we have **negative feedback**
    - If AB is positive *and* $AB >> 1$

$$G = \frac{A}{1+AB} \approx \frac{A}{AB} = \frac{1}{B}$$

  – gain is independent of the gain of the forward path A

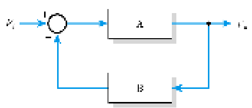
Negative feedback

- Negative feedback can be applied in many ways
  - X_i and X_o could be temperatures, pressures, etc.
  - here we are mainly interested in voltages and currents
- Is particularly important in overcoming **variability**
  - all active devices suffer from variability
    - their gain and other characteristics vary with temperature and between devices
  - we noted above that using negative feedback we can produce an arrangement where the gain is *independent* of the gain of the forward path
    - this gives us a way of overcoming problems of variability

Negative feedback – an example

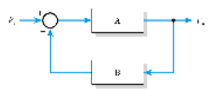
- Consider the following example
  Example: Design an arrangement with a stable voltage gain of 100 using a high-gain active amplifier. Determine the effect on the overall gain of the circuit if the voltage gain of the active amplifier varies from 100,000 to 200,000.

  We will base our design on our standard feedback arrangement



Negative feedback – an example (contd.)

- We will use our active amplifier for A and a stable feedback arrangement for B



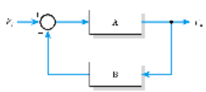
- Since we require an overall gain of 100 and

$$G = \frac{1}{B}$$

  we will use B **= 1/100 or 0.01**

Negative feedback – an example (contd.)

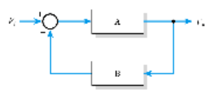
- Now consider the gain of the circuit when the gain of the active amplifier A **is 100,000**



$$\begin{aligned} G = \frac{A}{1+AB} &= \frac{100,\ 000}{1+(100,\ 000\times 0.01)} \\ &= \frac{100,\ 000}{1+1000} \\ &= 99.90 \\ &\approx \frac{1}{B} \end{aligned}$$

Negative feedback – an example (contd.)

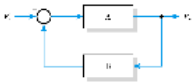
- Now consider the gain of the circuit when the gain of the active amplifier A **is 200,000**



$$\begin{aligned} G = \frac{A}{1+AB} &= \frac{200,\ 000}{1+(200,\ 000\times 0.01)} \\ &= \frac{200,\ 000}{1+2000} \\ &= 99.95 \\ &\approx \frac{1}{B} \end{aligned}$$

Negative feedback – an example (contd.)

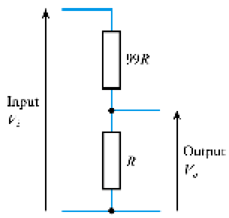
- Note that a change in the gain of the active amplifier of 100% causes a change in the overall gain of just 0.05 %



- Thus, the use of negative feedback makes the gain largely independent of the gain of the active amplifier
- However, it does require that *B* is stable
  - fortunately, *B* can be based on stable passive components

Negative feedback – an example (contd.)

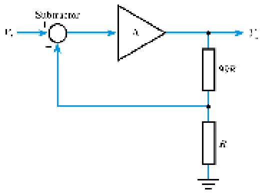
- Implementing the passive feedback path
  - to get an overall gain of greater than 1 requires a feedback gain *B* of less than 1
  - in the previous example the value of *B* is 0.01
  - this can be achieved using a simple potential divider



Negative feedback – an example (contd.)

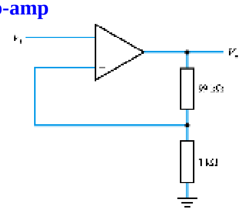
- Thus, we can implement our feedback arrangement using an active amplifier and a passive feedback network to produce a stable amplifier
- The arrangement on the right has a gain of 100 …

  … but how do we implement the subtractor?



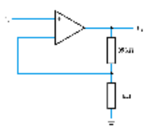
Negative feedback – an example (contd.)

- A differential amplifier is effectively an active amplifier combined with a subtractor. A common form is the **operational amplifier** or **op-amp**
- The arrangement on the right has a gain of 100.



Negative feedback – an example (contd.)

- In this circuit the gain is determined by the passive components and we do not need to know the gain of the op-amp
  - however, earlier we assumed that $AB >> 1$
  - that is, $A >> 1/B$
  - that is, **open-loop gain >> closed-loop gain**
  - therefore, the gain of the circuit must be much less than the gain of the op-amp



The effects of negative feedback

- **Effects on gain**
  - negative feedback produces a gain given by

$$G = \frac{A}{1 + AB}$$

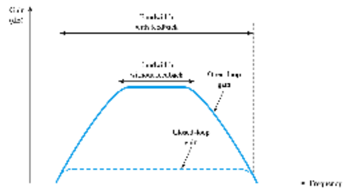
  - there, feedback *reduces* the gain by a factor of $1 + AB$
  - this is the price we pay for the beneficial effects of negative feedback

The effects of negative feedback (contd.)

- **Effects on frequency response**
  - from earlier lectures we know that all amplifiers have a limited frequency response and bandwidth
  - with feedback we make the overall gain largely independent of the gain of the active amplifier
  - this has the effect of increasing the bandwidth, since the gain of the feedback amplifier remains constant as the gain of the active amplifier falls
  - however, when the open-loop gain is no longer much greater than the closed-loop gain the overall gain falls

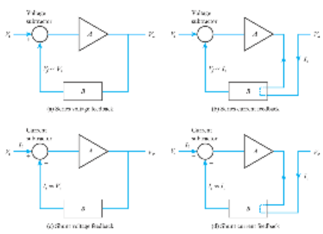
The effects of negative feedback (contd.)

- therefore the bandwidth *increases* as the gain is *reduced* with feedback
- in some cases the **gain x bandwidth = constant**



The effects of negative feedback (contd.)

- **Effects on input and output resistance**
  - negative feedback can be used in a number of ways.



The effects of negative feedback (contd.)

- negative feedback can either *increase* or *decrease* the input or output resistance depending on how it is used.
  - if the output voltage is fed back this tends to make the output voltage more stable by *decreasing* the output resistance
  - if the output current is fed back this tends to make the output current more stable by *increasing* the output resistance
  - if a voltage related to the output is subtracted from the input voltage this *increases* the input resistance
  - if a current related to the output is subtracted from the input current this *decreases* the input resistance
  - the factor by which the resistance changes is $(1 + AB)$
  - we will apply this to op-amps in a later lecture

The effects of negative feedback (contd.)

- **Effects on distortion and noise**
  - many forms of **distortion** are caused by a non-linear amplitude response
    - that is, the gain varies with the amplitude of the signal
  - since feedback tends to stabilise the gain it also tends to reduce distortion – often by a factor of $(1 + AB)$
  - **noise** produced *within* an amplifier is also reduced by negative feedback – again by a factor of $(1 + AB)$
    - note that noise already corrupting the input signal is *not* reduced in this way – this is amplified along with the signal

The effects of negative feedback (contd.)

- **Effects on stability**
  - from earlier we know that

$$G = \frac{A}{1 + AB}$$

  - so far we have assumed that A and B are positive real numbers
  - real amplifiers produce phase shifts at some frequencies
  - a phase shift of 180° represents an inversion of the gain
  - this will turn *negative* feedback into *positive* feedback
  - therefore, feedback has implication for **stability**
  - we will return to look at stability in later lectures

Negative feedback – a summary

- All negative feedback systems share some properties
  1. They tend to maintain their output independent of variations in the forward path or in the environment
  2. They require a forward path gain that is greater than that which would be necessary to achieve the required output in the absence of feedback
  3. The overall behaviour of the system is determined by the nature of the feedback path
- Unfortunately, negative feedback does have implications for the **stability** of circuits – this is discussed in later lectures

Key points

- Feedback is used in almost all automatic control systems
- Feedback can be either negative or positive
- If the gain of the forward path is *A*, the gain of the feedback path is *B* and the feedback is subtracted from the input then

$$G = \frac{A}{1 + AB}$$

- If *AB* is positive and much greater than 1, then $G \approx 1/B$
- Negative feedback can be used to overcome problems of variability within active amplifiers
- Negative feedback can be used to increase bandwidth, and to improve other circuit characteristics.