

Electronic Circuits

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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

2

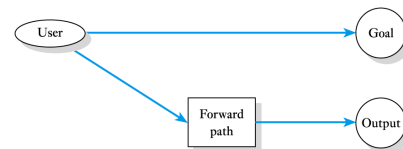
Introduction

- **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

3

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

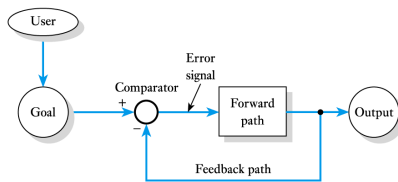


(a) An open-loop system

4

...Open-loop and closed-loop systems

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

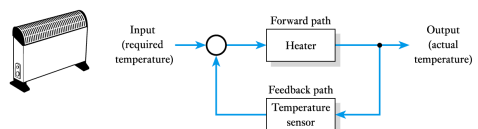


(b) A closed-loop system

5

Automatic control systems...

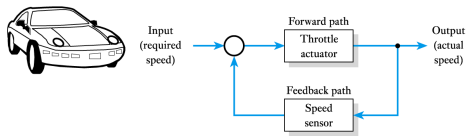
- Examples of automatic control systems:
 - temperature control using a room heater



6

...Automatic control systems...

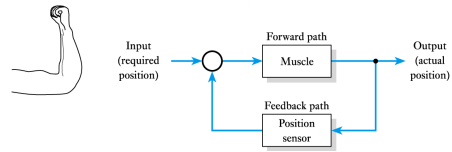
- Examples of automatic control systems:
 - cruise control in a car



7

...Automatic control systems...

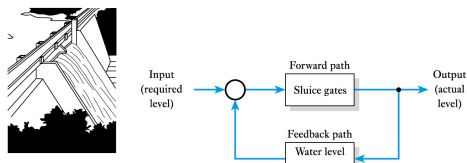
- Examples of automatic control systems:
 - position control in a human limb



8

...Automatic control systems

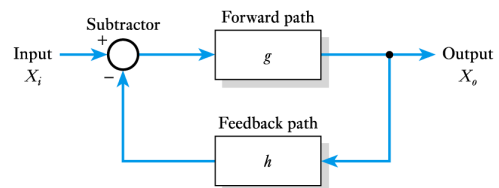
- Examples of automatic control systems:
 - level control in a dam



9

Feedback systems...

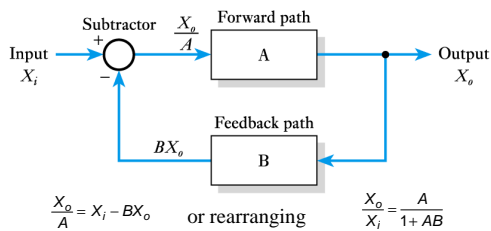
- A generalised feedback system



10

...Feedback systems...

- By inspection of diagram we can add values



11

...Feedback systems...

- 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**

12

...Feedback systems

- 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 $AB \gg 1$

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

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

13

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

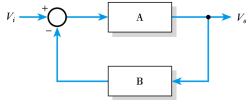
14

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.

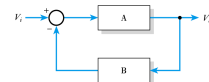
We will base our design on our standard feedback arrangement



15

...Negative feedback – an example...

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



- Since we require an overall gain of 100 and

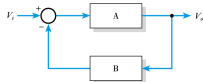
$$G = \frac{1}{B}$$

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

16

...Negative feedback – an example...

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

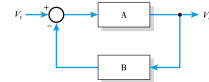


$$\begin{aligned} G &= \frac{A}{1 + AB} = \frac{100,000}{1 + (100,000 \times 0.01)} \\ &= \frac{100,000}{1 + 1000} \\ &= 99.90 \\ &\approx \frac{1}{B} \end{aligned}$$

17

...Negative feedback – an example...

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

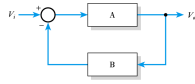


$$\begin{aligned} G &= \frac{A}{1 + AB} = \frac{200,000}{1 + (200,000 \times 0.01)} \\ &= \frac{200,000}{1 + 2000} \\ &= 99.95 \\ &\approx \frac{1}{B} \end{aligned}$$

18

...Negative feedback – an example...

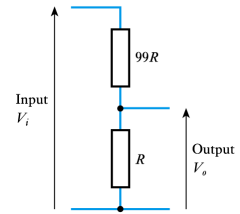
- Note that a change in the gain of the active amplifier of 100% causes a change in the overall gain of just 0.05 %
- Thus, the use of negative feedback makes the gain largely independent of the gain of the active amplifier
- However, it does require that B is stable
 - fortunately, B can be based on stable passive components



19

...Negative feedback – an example...

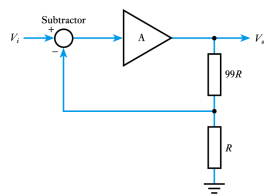
- Implementing the passive feedback path
 - to get an overall gain of greater than 1 requires a feedback gain B of less than 1
 - in the previous example the value of B is 0.01
 - this can be achieved using a simple potential divider



20

...Negative feedback – an example...

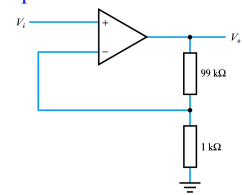
- Thus, we can implement our feedback arrangement using an active amplifier and a passive feedback network to produce a stable amplifier
- The arrangement on the right has a gain of 100 ...
 - ... but how do we implement the subtractor?



21

...Negative feedback – an example...

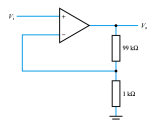
- A differential amplifier is effectively an active amplifier combined with a subtractor. A common form is the **operational amplifier** or **op-amp**
- The arrangement on the right has a gain of 100.



22

...Negative feedback – an example

- 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 $AB \gg 1$
 - that is, $A \gg 1/B$
 - that is, **open-loop gain \gg closed-loop gain**
 - therefore, the gain of the circuit must be much less than the gain of the op-amp



23

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

24

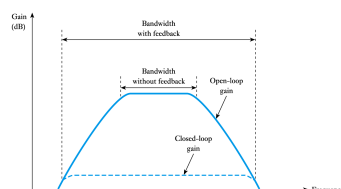
...The effects of negative feedback...

- 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

25

...The effects of negative feedback...

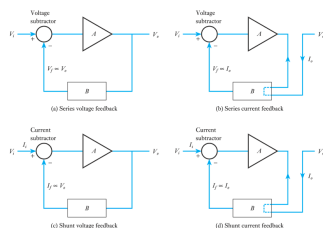
- therefore the bandwidth *increases* as the gain is *reduced* with feedback
- in some cases the gain x bandwidth = constant



26

...The effects of negative feedback...

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



27

...The effects of negative feedback...

- negative feedback can either *increase* or *decrease* the input resistance 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 $(1 + AB)$

28

...The effects of negative feedback...

- 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

29

...The effects of negative feedback

- 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

30

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 behavior of the system is determined by the nature of the feedback path
- Unfortunately, negative feedback does have implications for the **stability** of circuits

31

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.

32