NOTES FOR 6.002 LECTURE #19, APRIL 17, 2003

READ: 16.1 – 16.5

A NEW TOPIC: OPERATIONAL AMPLIFIERS.

FIRST A FEW WORDS ABOUT NEGATIVE FEEDBACK (ERROR CORRECTING FEEDBACK)

EXAMPLES: A THERMOSTAT IN AN OVEN (ON-OFF IN NATURE)

DRIVING ON A ROAD WITH CURVES

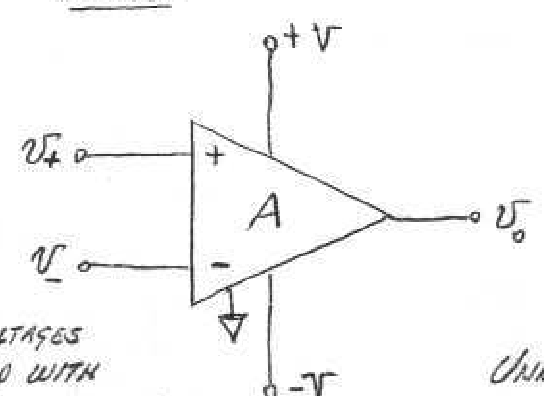
AUTOMATIC CONTROL OF A SHIPS' HEADING

IN EACH CASE A COMPARATOR (THERMOSTAT BIMETALLIC ELEMENT, EYES AND BRAIN, AN ANGLE SENSOR ON A GYROCOMPASS), DETECTS AN ERROR AND INSTRUCTS AN OUTPUT DEVICE (HEATING ELEMENT, STEERING WHEEL, RUDDER POSITION SETTING MECHANISM) TO RESPOND TO REDUCE THE ERROR.

AN OPERATIONAL AMPLIFIER COMBINES A COMPARATOR AND AN AMPLIFIER WHICH PRODUCES THE ELECTRICAL RESPONSE.

CIRCUIT DIAGRAM - TWO INPUTS (741 USED IN LAB 4)

SYMBOL



ALL VOLTAGES DEFINED WITH RESPECT TO GROUND

$\pm V$ COMMONLY $\pm$ 5-12 VOLTS

A IS THE VOLTAGE TRANSFER RATIO (A CONSTANT)

v_+, v_- ARE INPUT VOLTAGES

v_o IS THE OUTPUT VOLTAGE

UNDER APPROPRIATE CONDITIONS:

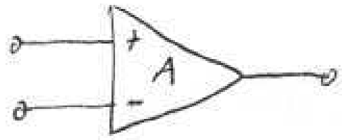
$$v_o = A(v_+ - v_-)$$

THIS IS A DIFFERENCE AMPLIFIER. IT RESPONDS NOT TO v_+ OR v_- BUT TO THEIR DIFFERENCE $(v_+ - v_-)$

A IS COMMONLY QUITE LARGE $A \sim 10^5$ TO 10^6 $\frac{\text{VOLTS}}{\text{VOLT}}$

IT REQUIRES NEGLIGIBLE CURRENT AT THE INPUTS. WE ASSUME ZERO INPUT CURRENT

USUALLY THE CIRCUIT SYMBOL IS SIMPLIFIED TO:



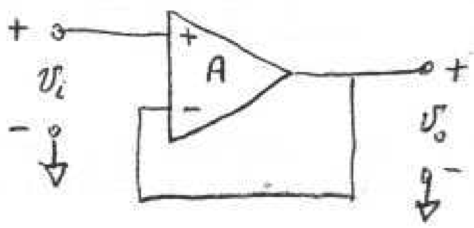
BUT REMEMBER THAT THIS CONTROL VALVE GETS ITS ENERGY FROM $\pm V$.

THE OP-AMP HAS DEFECTS: ITS GAIN A VARIES CONSIDERABLY FROM UNIT TO UNIT.
IT IS EXTRAORDINARILY TEMPERATURE SENSITIVE.

THE DEFECTS ARE DEALT WITH BY PUTTING NEGATIVE FEEDBACK AROUND THE OP-AMP.

DEMO

SIMPLEST NON-INVERTING CIRCUIT:



CONSIDER QUALITATIVE ACTION

ANALYSIS:

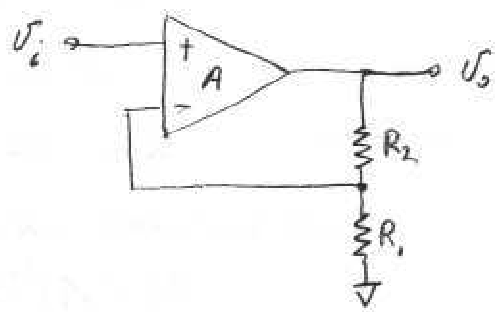
$$v_o = A(v_+ - v_-)$$

($v_+ = v_i$, $v_- = v_o$)

$$v_o = A v_i - A v_o$$

$$v_o(1+A) = A v_i \qquad \frac{v_o}{v_i} = \frac{A}{1+A} \cong 1$$

A MORE USEFUL NON-INVERTING CIRCUIT:



ANALYSIS:

$$v_o = A(v_+ - v_-)$$

$$v_+ = v_i$$

$$v_- = \frac{R_1}{R_1+R_2} v_o$$

$$v_o + A\frac{R_1}{R_1+R_2}(v_o) = A v_i$$

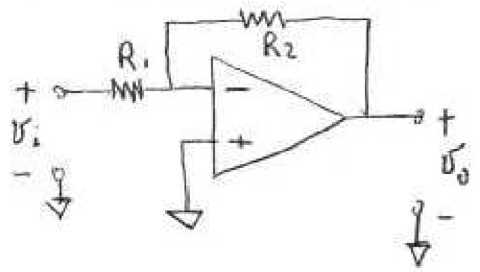
$$\frac{v_o}{v_i} = \frac{A}{1 + A\frac{R_1}{R_1+R_2}}$$

IF $A\frac{R_1}{R_1+R_2} >> 1 \qquad \frac{v_o}{v_i} = \frac{R_1+R_2}{R_1}$

THIS APPROXIMATION IF THE OPEN LOOP GAIN A IS MUCH GREATER THAN THE GAIN WITH FEEDBACK $\frac{R_1+R_2}{R_1}$, WHICH CAN EASILY BE SET (VIA R_1) TO BE AS LARGE AS 10^3 OR SO.

DEMO

THERE IS ALSO AN INVERTING VERSION:



ANALYSIS:

$$v_0 = A(v_+ - v_-)$$

($v_+ = 0$)

$$v_- = v_i \frac{R_2}{R_1+R_2} + v_0 \frac{R_1}{R_1+R_2}$$

SUBSTITUTE AND SOLVE

$$\frac{v_0}{v_i} = -\frac{A\frac{R_2}{R_1+R_2}}{1+A\frac{R_1}{R_1+R_2}} \cong -\frac{R_2}{R_1}$$

CONSIDER QUALITATIVE ACTION

THE APPROXIMATION IS VALID IF $\frac{AR_2}{R_1+R_2} \gg 1$

THE AMPLIFYING RANGE AT THE OUTPUT IS LIMITED BY $\pm V$

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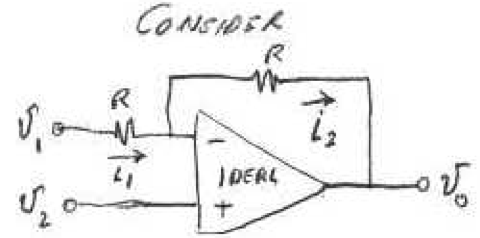
USEFUL SIMPLIFYING APPROXIMATIONS:

<u>THE IDEAL OP-AMP</u> $A \to \infty$ WHICH MEANS ANY FINITE OUTPUT v_0 CAN BE DEVELOPED WITH AN INFINITESIMAL VOLTAGE DIFFERENCE AT THE INPUT I.E $v_+ \cong v_-$

CONSIDER



ANALYSIS: $v_+ = v_-$

$i_1 = i_2$ (NO OP-AMP INPUT CURRENT)

THUS

$$\frac{v_1 - v_2}{R} = \frac{-v_0}{R} \quad \text{OR} \quad v_0 = v_1 - v_2$$

WHICH ILLUSTRATES ANOTHER USEFUL CONCEPT IN THE INVERTING CONNECTION: THE "CURRENT MIRROR" $i_1 = i_2$

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NOTE THAT ALL THIS ANALYSIS EMBODIES A CIRCUIT MODEL FOR THE OP AMP: