

LECTURE 9

LECTURE NOTES: JANUARY 31, 2002

REVIEW.....	1
OPERATIONAL AMPLIFIERS: INTRODUCTION	2
AMPLIFIER APPLICATION: MAGNETIC DISK STORAGE “READ CHANNEL”	2
THE OPERATIONAL AMPLIFIER SYSTEM.....	6
OPERATIONAL AMPLIFIER CHARACTERISTICS	7
OPERATIONAL AMPLIFIER CIRCUIT MODEL	9
AMPLIFIER CIRCUIT LIMITATIONS.....	10
NEGATIVE FEEDBACK PRINCIPLES.....	10
OPERATIONAL AMPLIFIER CIRCUIT APPLICATION.....	14
IDEAL OPERATIONAL AMPLIFIER CIRCUITS: NON-INVERTING VOLTAGE AMPLIFIER	15
IDEAL OPERATIONAL AMPLIFIER CIRCUITS: UNITY GAIN VOLTAGE AMPLIFIER PSPICE DEMONSTRATION	18
IDEAL OPERATIONAL AMPLIFIER CIRCUITS: NON-INVERTING VOLTAGE AMPLIFIER PSPICE DEMONSTRATION	21
OPERATIONAL AMPLIFIER NON-IDEAL BEHAVIOR: BIAS SUPPLY LIMITS.....	22
NON-IDEAL OPERATIONAL AMPLIFIERS.....	24
OPERATIONAL AMPLIFIER APPLICATIONS: FREQUENCY-SELECTIVE FILTER.....	27
IDEAL OPERATIONAL AMPLIFIER CIRCUIT	30

REVIEW

1. Principle of Superposition
2. Source Equivalents
3. Thevenin and Norton Equivalent Circuits
4. Computation of a Thevenin Equivalent for Circuits with Independent Sources
5. Computation of a Thevenin Equivalent for Circuits with Dependent Sources

OPERATIONAL AMPLIFIERS: INTRODUCTION

- In EE10, we have relied on ideal circuit elements, independent and dependent voltage sources and current sources. Prior to several critical inventions, such ideal elements were not possible to implement in reality.
- However, in this next topic, we will be learning about Operational Amplifiers that allow us to design circuits with precise and flexible response. These systems can implement the near-ideal elements we have been using.
- Operational amplifiers are core elements to electronics technology, appearing in:
 - Communications
 - Consumer Electronics
 - Computing Systems
 - Biomedical Electronics
 - Control Systems for Transportation
 - Instrumentation
- An excellent example of the applications of Operational Amplifiers appears in Magnetic Disk Storage.

AMPLIFIER APPLICATION: MAGNETIC DISK STORAGE “READ CHANNEL”

- Operational amplifiers are critical in modern data storage applications.
- The history of digital data storage might be said to begin with the punched card, invented by Jacquard to control a loom. Hollerith machines followed in 1884 with punched cards having individual records consisting of a few tens of characters could be written and read by a relatively simple machine.
- Punched paper tape followed this in about 1940.
- Magnetic methods for storing binary data in the form of two polarities of magnetization of a structure appeared in the late 1940s. The first magnetic disks appeared in 1957.
- Magnetic disk storage is now fundamental to modern computing. This provides fast access to terabytes data libraries. Virtually all of the modern world’s data reaches magnetic storage.

- Magnetic storage systems are based on the electromechanical disk drive system, shown below. We will also have an example to view in class.

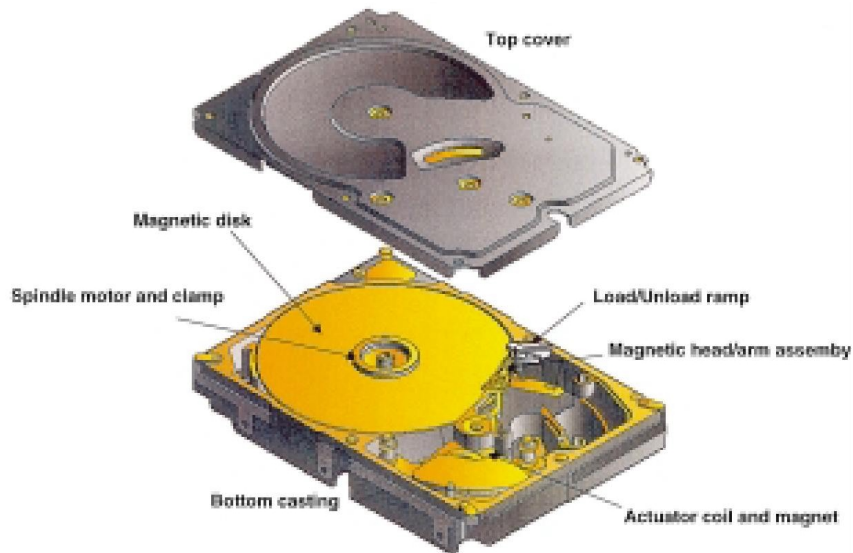


Figure 1. Magnetic Disk Drive System

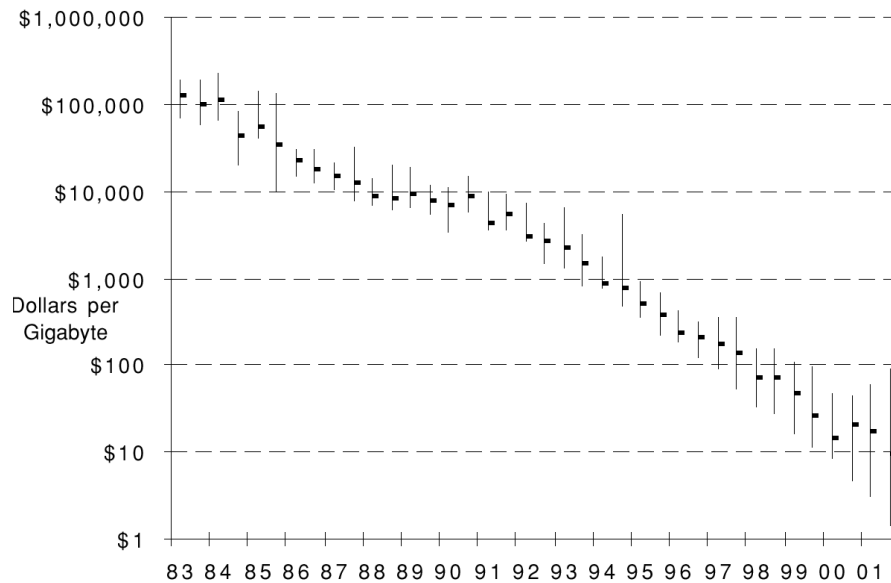


Figure 2.. Cost of memory in magnetic storage disk drive versus time

- Magnetic storage depends on the ability to encode data by magnetizing microscopic regions of the magnetic disk in a pattern and then subsequently “read” the polarity of these sections to decode the stored data.

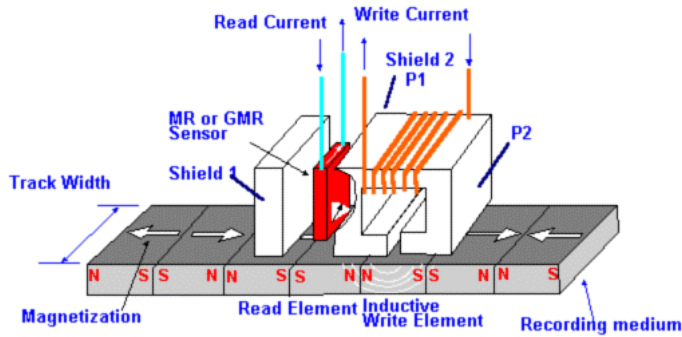


Figure 3. Schematic view of the magnetic disk "read head".

- The magnetic storage data recovery system depends on the characteristics of the read head shown above.
- This sweeps over the head at high speed, sampling the changing magnetic field previously written onto the disk.
- A “magnetoresistive” MR head is the system used at present.

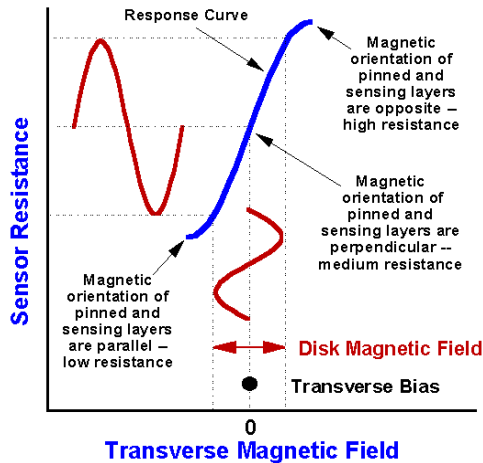


Figure 4. Response of the disk drive magnetoresistive magnetic field transducer

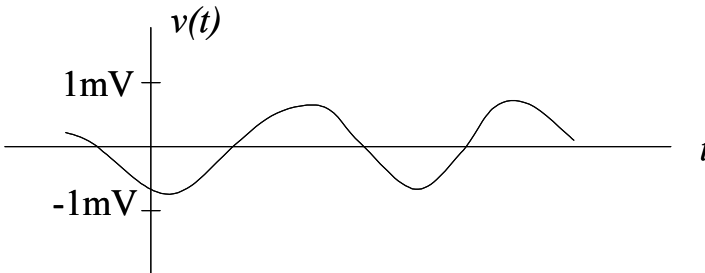


Figure 5. Signal derived from Magnetoresistive (MR) Read Head

- Figure 5 indicates the signal that the read head system produces. This contains data, that must now be extracted.

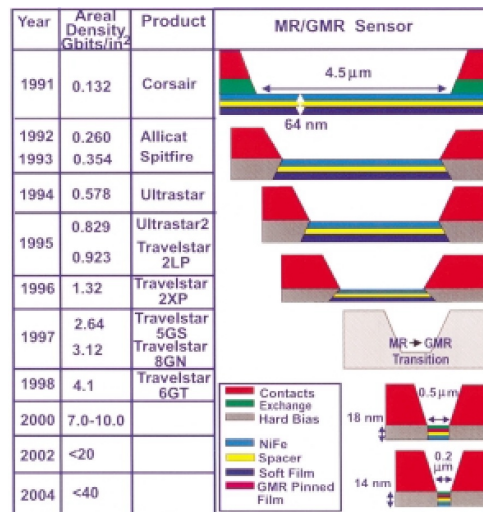


Figure 6. Past and expected progress in storage density and read head size.

- Read head technology progress has driven increased data storage density.

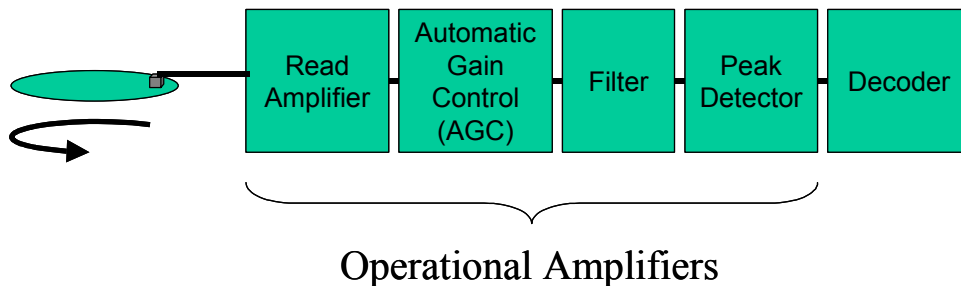


Figure 7. A schematic view of the critical disk drive Read Channel

- The circuit system that is used for extracting data encoded on a disk is referred to as the read channel.
- Read channel performance determines data rate and data capacity for disk drive – pacing progress in the entire industry.
- Current read channel bandwidths are approaching 1 GHz.
- The challenges include:
 - Low and variable signal level

- Complex data encoding
- Extreme accuracy requirements for signal processing and data detection.
- Components of the read channel require the performance of operational amplifiers:
 - The magnetoresistive read head. This can be viewed (for this discussion) to be a resistor with a time dependent resistance. The read head is supplied (biased) with a current that, in turn, generates a potential that depends on resistance and is, therefore, also time dependent. This signal, as shown in Figure 5, carries the encoded data.
 - Read Amplifier: This is the most important element in determining the resolution of the read channel. Its self-generated noise level will set the minimum noise level for the entire system.
 - Automatic Gain Control Amplifier (AGC). This operational amplifier system must adjust the voltage gain of the entire system to accommodate the variations in signal amplitude that result due to variations in the spinning disk properties and read head flying height.
 - Filter: This is an operational amplifier designed to select frequency components of the signal that are of interest, and reject others. See Appendix for example.
 - Peak Detector: This may be the last operational amplifier in the channel (for this simple example). This system detects the arrival of a maximum (peak) in the signal and provides a corresponding indicating signal at its output.
 - Decoder: This is the first stage of many digital components that is responsible for digital data signal processing and data recovery.

THE OPERATIONAL AMPLIFIER SYSTEM

- The Operational Amplifier carries five terminals:
 - Two input voltage signal terminals
 - Inverting Input Terminal
 - Non-Inverting Input Terminal
 - One output voltage signal terminal.
 - Two Supply Terminals.
- The supply bias values are static signals. They are labeled:

- V_{DD} for the positive supply terminal
- V_{SS} for the negative supply
- Typical supply values are:
 - $18V > V_{DD} > 1.5V$
 - $-18V < V_{SS} < -1.5V$
- Typical supply currents are:
 - $10\mu A$ for a micropower system to 10 mA for a typical general purpose operational amplifier, to many amperes for a power operational amplifier (for audio or robotic system applications).
- The Operational Amplifier circuit symbol is:

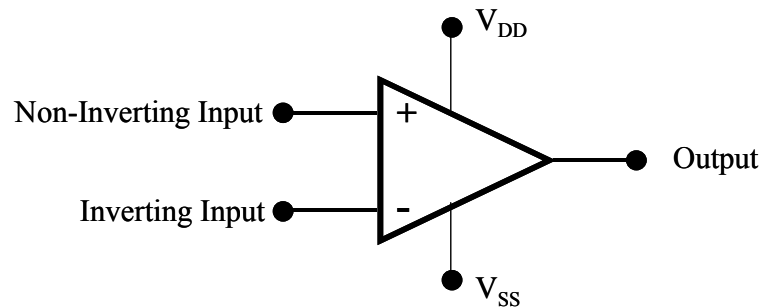


Figure 8. Operational Amplifier Circuit Symbol

- Design goals for Operational Amplifiers include:
 - Low power
 - Wide frequency response
 - High gain values
 - High linearity
 - High stability over temperature and over variable power supplies.
 - Tolerance to fabrication variations.

OPERATIONAL AMPLIFIER CHARACTERISTICS

- The most important Operational Amplifier characteristics regard its Voltage Amplification

- The Operational Amplifiers is a Differential Amplifier.
- To understand this, we will examine a Node Voltage model of the Operational Amplifier.
- The Node Voltages measured relative to a common reference potential. This reference potential may be V_{SS} .

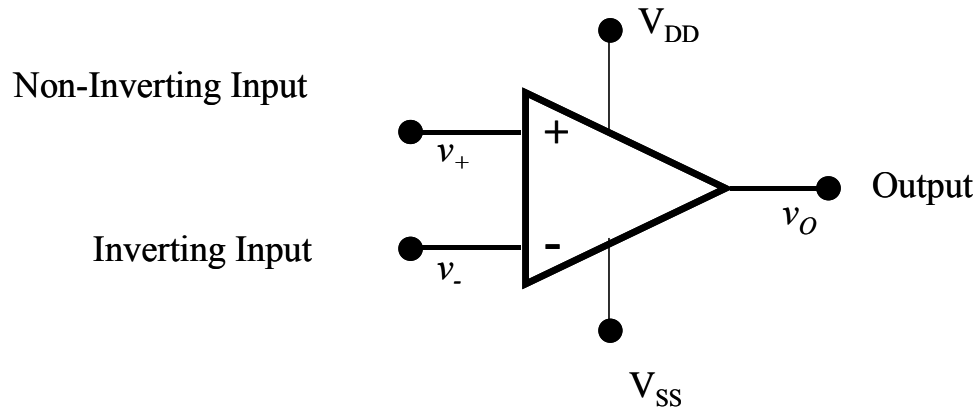


Figure 9. Operational Amplifier with Node Voltages labeled.

- Non-Inverting and Inverting Inputs and Output are labeled as above.
 - Inverting Input Terminal: v_-
 - Non-Inverting Input Terminal: v_+
- Note that supply voltages are constant.
- The critical output characteristic is:

$$v_O = A_V (v_+ - v_-)$$

- A_V is the Voltage Gain. This is referred to as **Open Loop Voltage Gain**
- Note that output depends only on the voltage *difference*.
- Note that the output does not depend on the value of either input voltage relative to the reference.
- Note that output does not depend on the supply voltages.

OPERATIONAL AMPLIFIER CIRCUIT MODEL

- We must construct a circuit model for the Operational Amplifier for the purposes of design and analysis.
- Here we may (with later verification) neglect the role of the voltage supplies

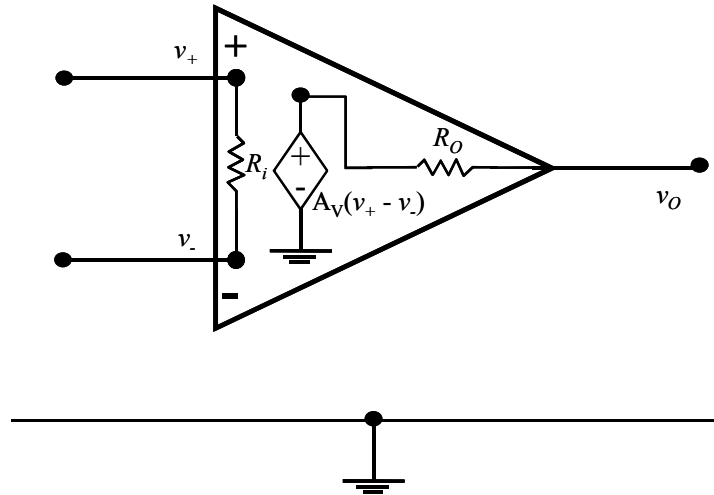


Figure 10. Operational Amplifier Model including input and output resistances and using a Dependent Source

- Further, we may model the voltage amplification function with a Dependent Source
- Also, we may include the resistances that appear with actual operational amplifier systems. This model is shown in Figure 10.
- Note that this includes an Output Resistance, R_O , and an Input Differential Resistance, R_i .
- Typical Parameters for Operational Amplifiers include:
 - Voltage Gain = $10^3 - 10^6$
 - Input Resistance = $10^6 - 10^{11}$
 - Output Resistance = 100Ω (as low as $10^{-6}\Omega$ for some closed loop circuits)
 - Frequency Response = Operational amplifiers are developed for operation up to 1 GHz.

- We are already in a position to design and analyze operational amplifier circuits.
- First, we must discuss Operational Amplifier Circuit Applications

AMPLIFIER CIRCUIT LIMITATIONS

- Amplifier applications demand control over many critical parameters. However, these parameters may not be stable or reproducible for amplifiers implemented with conventional semiconductor device technologies. We may consider the gain of an amplifier circuit. It shows the following typical variation:
 - Fabrication tolerance leads to a part to part variation of at least 10x
 - Non-linearity in response over the input range may also produce a 10x variation
 - Temperature variation may lead to 2X – 10X variations in gain.
 - Supply bias variations may cause gain to vary by 10 percent
 - Input signal frequency variations also leads to 10X or great variations in gain.
- How do we obtain extreme (i.e. 0.1 percent) accuracy in the presence of all these issues?
- Note critical point: we may control resistor (and capacitor) values accurately, however, the active amplifier (semiconductor transistor) components are fundamentally less accurately controlled.
- Primary goal: Design semiconductor device circuits with characteristics that depend on resistance *ratios* or capacitor *ratios* not on semiconductor device specific characteristics.
- We will use the principle of Negative Feedback.

NEGATIVE FEEDBACK PRINCIPLES

- The concept of negative feedback was a rare breakthrough – an easily expressed concept that has had profound implications for many engineering disciplines, technologies, and products.
- This is an example of where a designer took a path opposite to the conventional direction and pursued it very far, and developed a revolutionary change in both circuits and systems.
- Harold S. Black (born 1893) was an engineer at AT&T. For six years he had been trying to develop a means to create a linear amplifier. This is an amplifier that provides an output signal directly proportional (linearly related) to the input signal.

- Up until that time, no linear amplifier existed. The lack of linearity was an immense barrier to amplification of signals for measurement and communication systems. A large world of electronics from communication, consumer electronics, defense and medical systems were waiting for a linear circuit element.
- Vacuum tube amplifiers (and the transistor to be invented 25 years later) were fundamentally non-linear and not able, alone, to produce linear systems. Also, these systems all suffered from characteristics where the output signal of the amplifier depended on the value of the output load resistor, a further hindrance to design.
- In 1927, while riding a ferry to his office one morning, the idea of negative feedback occurred to Harold Black.

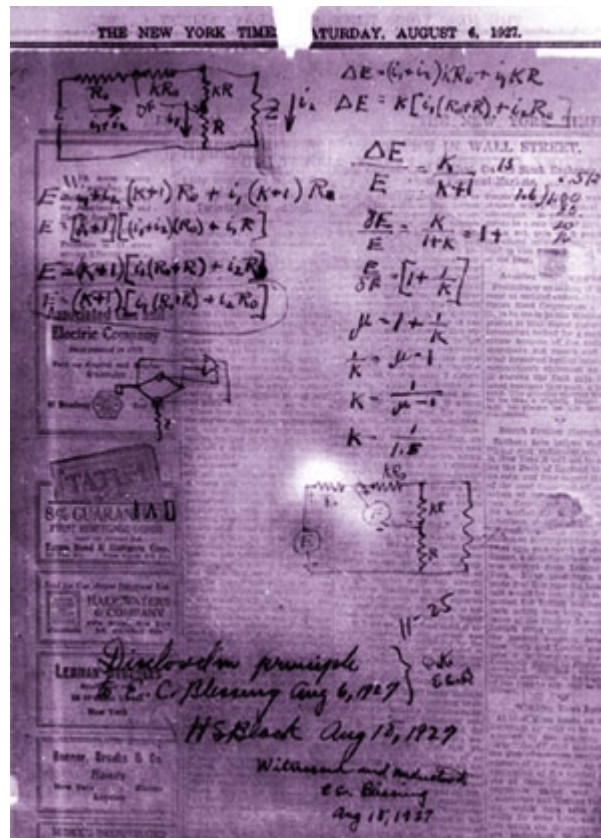


Figure 11 The copy of the New York Times that Harold S. Black wrote down his idea of Negative Feedback, while commuting on a ferry in New York City. This is one of the most valuable ideas in Electrical Engineering.

- Lets examine the benefits of negative feedback as it may have appeared to Harold Black.
- Now, first, lets examine a circuit that is designed to produce a simple Unity Gain amplification. We will discuss the importance of Unity Gain amplifiers more fully later. However, this is an ideal start for our discussion.

- Below we have a circuit operating with a dependent voltage source, a series resistance, associated with our source, and a load resistance, R_L .
- This amplifier response is determined by the voltage divider equation, and by the dependent source.
- Lets examine this.

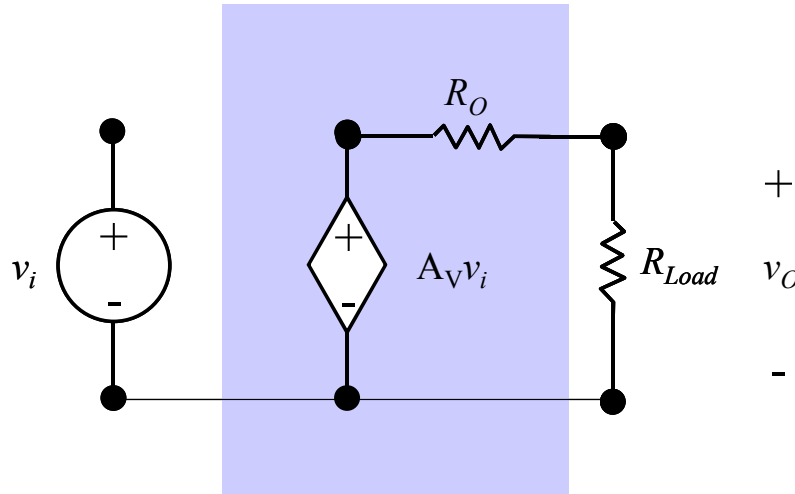


Figure 12. A simple amplifier circuit we will use to demonstrate the capability of negative feedback. This circuit is in “closed loop” form. Specifically, Negative Feedback has been applied !

- The output signal depends on input voltage as:

$$v_O = A_V v_i [R_{Load} / (R_O + R_{Load})]$$

- Note that we can compute an overall voltage gain. So that,

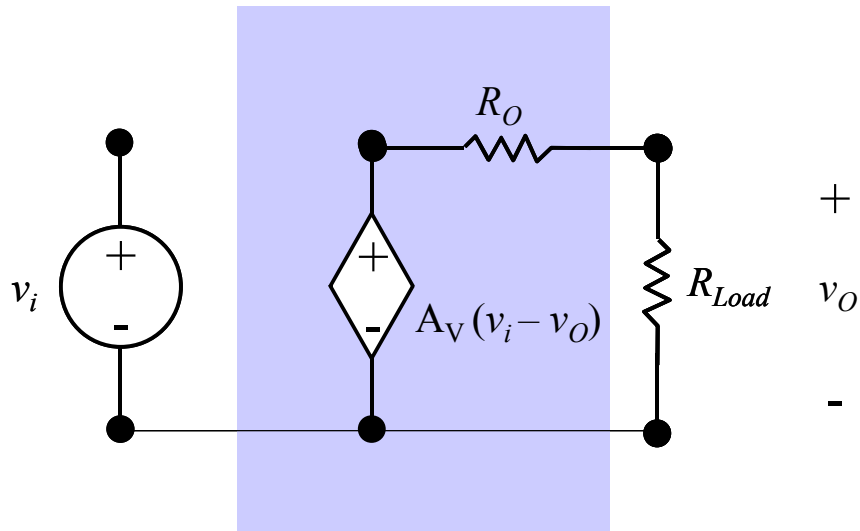
$$v_O = A_{Amp} v_i,$$

- where

$$A_{Amp} = A_V [R_{Load} / (R_O + R_{Load})]$$

- Now, note that this gain, which we may wish to set to the particular value (for example, $A_{Amp} = 1$) now requires that we have knowledge of R_{Load} and accurate control over A_V .
- But, this is *not possible*.
- First, it is our customer that who tell us what R_{Load} is. She or he will have specific goals to meet that constrain the choice of R_{Load} .
- Second, A_V depends on physical properties of the circuit elements and these are variable.

- Finally, we find that unfortunately, A_V is not a constant and itself may vary with v_i hence, we observe nonlinear response.
- Harold Black's idea was to change this circuit so that *part of the output signal was applied to the input*. This was an enormous departure from previous work and would normally have been considered ill-advised.
- His new circuit would appear:



- Now, the output signal dependence on input voltage is not at all immediately obvious. We must calculate.
- Again, the output voltage depends on a voltage divider structure. The output voltage in terms of input voltage will be:

$$v_O = A_V (v_i - v_O) \left(\frac{R_{Load}}{R_{Load} + R_O} \right)$$

- Now, we see that output voltage appears on both sides of this equation. Initially, this may appear innocuous. But, let's solve for the output signal.

$$v_O = A_V v_i \left(\frac{R_{Load}}{R_{Load} + R_O} \right) - A_V v_O \left(\frac{R_{Load}}{R_{Load} + R_O} \right)$$

- or

$$v_O \left[1 + A_V \left(\frac{R_{Load}}{R_{Load} + R_O} \right) \right] = A_V v_i \left(\frac{R_{Load}}{R_{Load} + R_O} \right)$$

- and

$$v_O = \frac{v_i}{\left[1 + \left(\frac{R_{Load} + R_O}{A_V R_{Load}} \right) \right]}$$

- This equation is very important – it displays a characteristic form that we will see repeatedly in Negative Feedback problems.
- Note that the gain, A_V , appears in the denominator of the term, itself appearing in the denominator of the expression determining output voltage.
- Now, consider the case where we strive to make A_V very large, through design of the dependent source system.
- Then, in this limit, the characteristic for this amplifier becomes:

$$v_O = v_i$$

- Now, the actual value of gain and the load resistor value *does not determine* output signal. We have achieved a system that is both accurate and linear in one simple step. Specifically, $A_{Amp} = 1$.

- It is very important for us to stop here and discuss the intuition required to understand this.

- There are many other benefits as we will discuss.
- Note that this circuit is an *operational amplifier* circuit.

OPERATIONAL AMPLIFIER CIRCUIT APPLICATION

- Now, the operational amplifier is not useful when operating independently. Its nonlinear response and extreme gain characteristics severely limit its applicability. In fact, it is rarely if ever applied without supporting components.
- However, it was developed for and is ideal for use in circuits with Negative Feedback.

IDEAL OPERATIONAL AMPLIFIER CIRCUITS: NON-INVERTING VOLTAGE AMPLIFIER

- Now, let's consider some of the most important operational amplifier circuits.
- With our experience in circuit analysis with Dependent Sources, we can perform basic analyses with Node Voltage methods quite rapidly.
- We will perform basic analyses and then compare them with PSpice analysis here in lecture.
- The first circuit we will examine will be the Non-Inverting Voltage amplifier.
- The circuit is shown below.

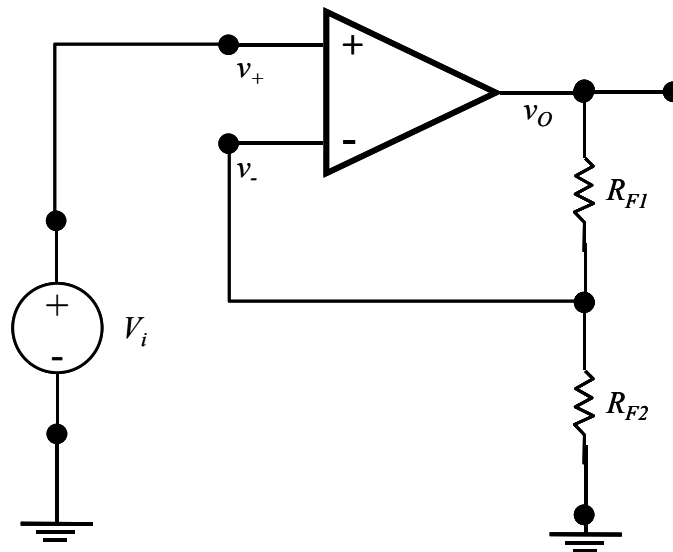


Figure 13. The Non Inverting Operational Voltage Amplifier

- Now, let's add one non-ideal feature to this Operational Amplifier. This will be its output resistance, R_O .
- So, let's insert the true model elements for the Operational Amplifier. The new circuit appears:

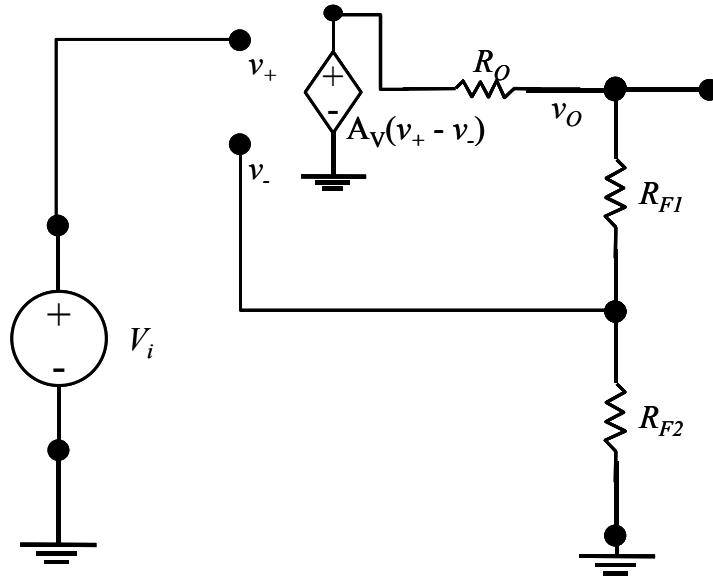


Figure 14. The Non Inverting Voltage Amplifier model including Output Resistance, R_O .

- We can use Node Voltage methods to solve for output voltage. It is good practice to examine the form of the equations in these typical circuits – we will find a recurring form.

$$\frac{A_V(v_+ - v_-) - v_O}{R_O} - \frac{v_O}{R_{F1} + R_{F2}} = 0$$

- Also, we have from the voltage divider equation,

$$\frac{v_O - v_-}{R_{F1}} - \frac{v_-}{R_{F2}} = 0$$

- And, further,

$$V_i = v_+$$

- Note that all the voltages are node voltages measured relative to the reference and their terminals at the node are defined as positive (as usual).
- Now, from the second equation, we have just the voltage divider expression resulting from this:

$$v_- = v_O \frac{R_{F2}}{R_{F1} + R_{F2}}$$

- So, manipulating our first equation, and substituting for V_i ,

$$\frac{A_V V_i}{R_O} - \frac{A_V v_-}{R_O} - \frac{v_o}{R_O} = \frac{v_o}{R_{F1} + R_{F2}}$$

- Now, we want an equation in terms of output and input voltage only. But, we have the voltage divider system providing our feedback signal and definition of v_- .
- So,

$$\frac{A_V V_i}{R_O} - \frac{A_V v_o R_{F2}}{R_O (R_{F1} + R_{F2})} - \frac{v_o}{R_O} = \frac{v_o}{R_{F1} + R_{F2}}$$

- Manipulating,

$$\frac{A_V V_i}{R_O} = v_o \left[\frac{A_V R_{F2}}{R_O (R_{F1} + R_{F2})} + \frac{1}{R_{F1} + R_{F2}} + \frac{1}{R_O} \right]$$

- Finally, we obtain our output voltage in terms of input voltage:

$$v_o = \frac{\frac{A_V V_i}{R_O}}{\left[\frac{A_V R_{F2}}{R_O (R_{F1} + R_{F2})} + \frac{1}{R_{F1} + R_{F2}} + \frac{1}{R_O} \right]}$$

- Now, at this stage, note which terms in the denominator contain the open loop gain factor.
- We can multiply through by the factor of R_O / A_V . This yields

$$v_o = \frac{V_i}{\left[\frac{R_{F2}}{(R_{F1} + R_{F2})} + \left(\frac{1}{A_V} \right) \left(1 + \frac{R_O}{R_{F1} + R_{F2}} \right) \right]}$$

- This expression is characteristic of Negative Feedback Operational Amplifier *transfer functions* that express the output signal of a circuit in terms of an input signal.
- Note, that in the limit where A_V is large, we have,

$$v_o = V_i \frac{(R_{F1} + R_{F2})}{R_{F2}}$$

- Now, let's discuss the Negative Feedback principle here.
- First, consider the value of the Inverting Input voltage, this is just determined by the

Voltage Divider equation.

$$v_- = v_O \frac{R_{F2}}{R_{F1} + R_{F2}}$$

- Now, a small fraction of the output voltage is applied to the Inverting Input.

- It is very important for us to stop here and discuss the intuition required to understand this.

- But, the amplifier output voltage is determined by the difference between this and the Input Voltage applied to the Non-Inverting Input.
- We can see that for large gain, this circuit will stabilize, at a value where the two amplifier input terminals are nearly equal in voltage, and this demands a relationship between v_O and V_i set by the voltage divider relation.

- Lets walk through this process of stabilization. We will discuss the approach to stability and how this circuit may recover from a disturbance and return to stability.

- Now, there are other critical features of this circuit.
- Independence of the Output Voltage on Open Loop Gain:
 - Note that in the limit of large gain, the output voltage is insensitive to variations in gain.
- Independence of the Output Voltage on Output Resistance
 - Note that in the limit of large gain, the output voltage is insensitive to the value of the Output Resistance, R_O .

**IDEAL OPERATIONAL AMPLIFIER CIRCUITS: UNITY GAIN VOLTAGE AMPLIFIER
PSPICE DEMONSTRATION**

- We will begin our PSpice analysis by first examining an open loop circuit – similar to the ones that H. S. Black would have encountered.
- We will construct a simple equivalent circuit model of an operational amplifier. We will use a Dependent Source. This is an “E” device in the PSpice Analog Library. This is shown below. Also, in this Operational Amplifier, we will use an Output Resistance, $R_1 = 100\Omega$
- This circuit will also contain an output load resistor.

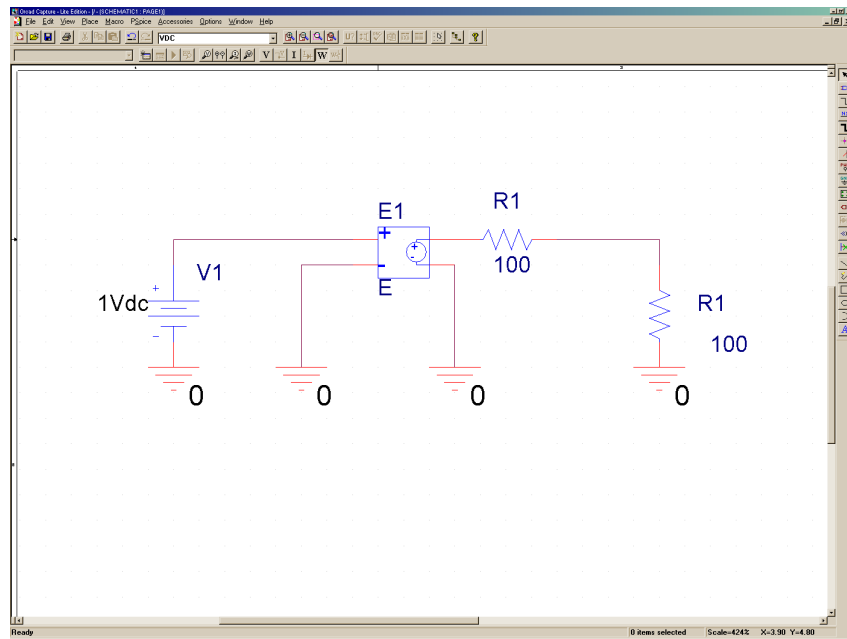


Figure 15. An open Loop Operational Amplifier model. The Resistor R1 represents the Output Resistance of the Operational Amplifier

- Now, after having constructed this circuit, we will need to create and configure the Simulation Profile (as per the Tutorial). We will select bias point.

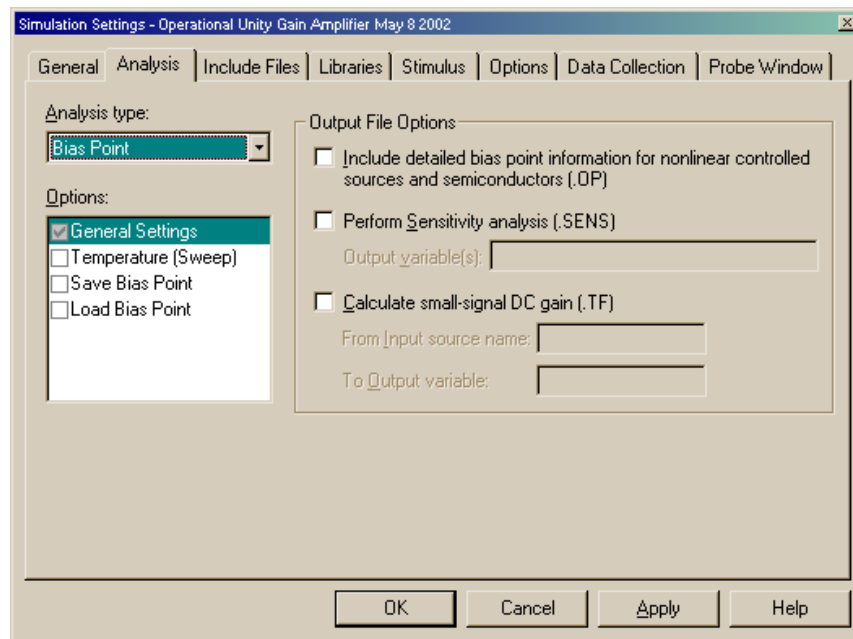


Figure 16. Simulation Profile for this analysis.

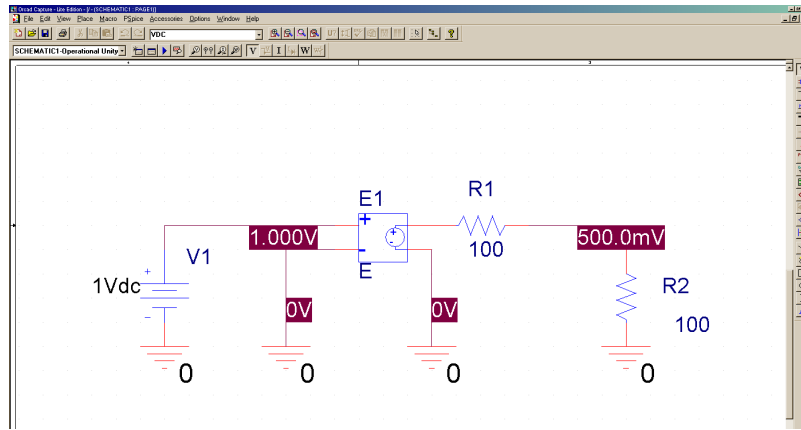


Figure 17. Output of the PSpice simulator

- At this point, we will adjust the gain of the Dependent Source to be unity.
- Now, note that in this open loop system, due to the presence of the Load Resistor, R2, there is an inherent voltage drop at the output. While the input is 1.0V, the output is 0.5V. This can be regarded as an error.
- Lets introduce Negative Feedback and large Open Loop gain, A_v .

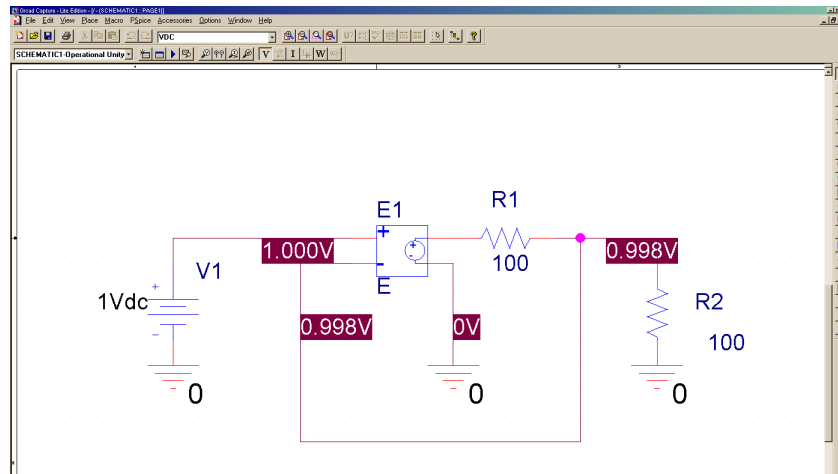


Figure 18. Our example circuit, now operating in the Unity Gain configuration and with Open Loop gain of 1000.

Item	Value	Color	Designator	Gain	Grapher	Implementation	Implementation Path	Implementation Type	Name	Part Reference	PCB Footprint	Power Pins Visible	Primitive	PlaceOnly
1	SCHEMATIC1:PAGE1:E1	Default	1000	1000	Normal	Implementation	Implementation Path	Implementation Type	Implementation	00013	E1	PCB Footprint	Power Pins Visible	DEFAULT
2	E1	Default	1000	1000	Normal	Implementation	Implementation Path	Implementation Type	Implementation	00013	E1	PCB Footprint	Power Pins Visible	DEFAULT

Figure 19. Setting the "E" Dependent Voltage source to a Gain of 1000

- Now, we can experiment with this circuit. Lets try the following experiments:
 - Change Open Loop gain and observe the effect on the output
 - Change the Output Resistance
- Lets compare these results with the analytical results.

**IDEAL OPERATIONAL AMPLIFIER CIRCUITS: NON-INVERTING VOLTAGE
AMPLIFIER PSpice DEMONSTRATION**

- Now, we will consider the Non-Inverting Voltage Amplifier. The PSpice circuit drawing is shown below.
- We will begin by setting the Dependent Source gain to 1000.

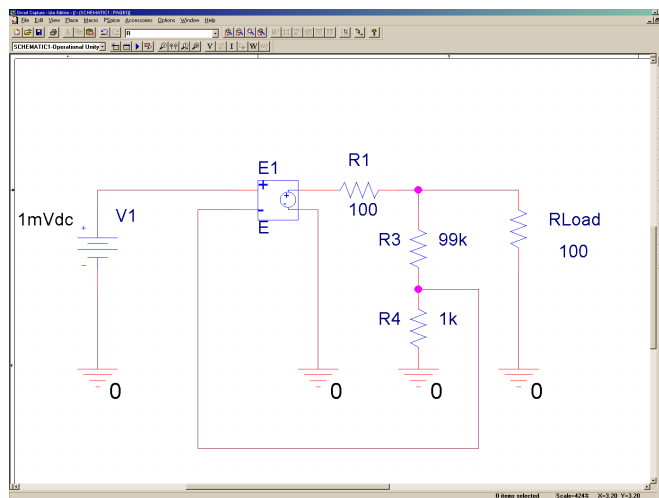


Figure 20. Non-Inverting Voltage Amplifier

- Lets compare this circuit with our analytical result.
 - What will be the system gain, (v_o/v_i) ?

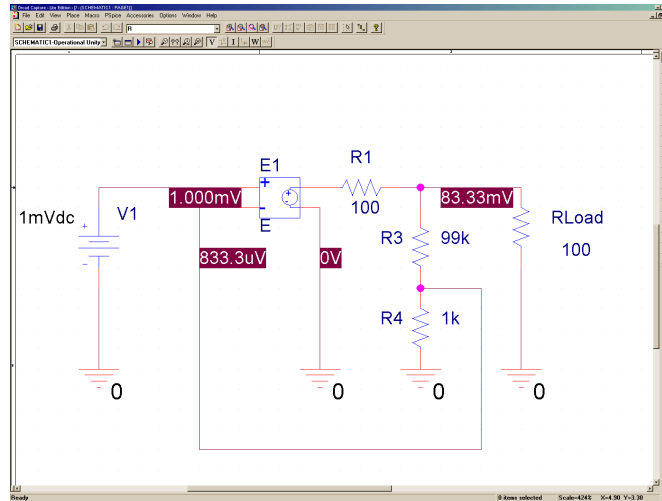


Figure 21. Non Inverting Amplifier Simulation results.

- Now, we can experiment with this circuit as well. Lets try the following experiments:
 - Change Open Loop gain and observe the effect on the output
 - Compare this with our analytical results
 - Change the Output Resistance

OPERATIONAL AMPLIFIER NON-IDEAL BEHAVIOR: BIAS SUPPLY LIMITS

- In order to understand the non-ideal behavior of Operational Amplifiers, we must refer to actual circuit implementations and examine these briefly. Figure 22 shows a typical Operational Amplifier circuit.
- This circuit is supplied with V_{DD} and V_{SS} voltages.
- These supply bias values determine the range of excursion of the output voltage and the range of linearity
- The output voltage, v_O , may not exceed the supply limits. In fact, typically the output voltage range is slightly less than the full voltage supply range.

$$V_{DD} > v_O > V_{SS}$$

- Specifically, for

$$V_{DD} > A_V (v_+ - v_-) > V_{SS}$$

- the circuit behaves in a linear fashion with

$$v_O = A_V (v_+ - v_-)$$

- But, if the output signal approaches one of the supply bias values, the output will “saturate” (remain fixed at and not exceed) this value.

- Specifically, for

$$A_V (v_+ - v_-) \leq V_{SS}, \text{ then } v_O \approx V_{SS}$$

$$A_V (v_+ - v_-) \geq V_{DD}, \text{ then } v_O \approx V_{DD}$$

- We will illustrate this with PSpice.
- However, we must always design to ensure that the output voltage “swing” does not approach the region of saturation. Fortunately, this is quite large for well-designed operational amplifiers.
- Now, in design and drawing of circuits with operational amplifiers, we suppress the voltage supplies.
- We also suppress the non-ideal nature of the voltage limitations.
- Then, when a problem is completely solved, we will check and verify to determine if the circuit operation is maintained within its linear range.
- Thus, we can proceed with simplified circuit diagrams, for parts of our work.

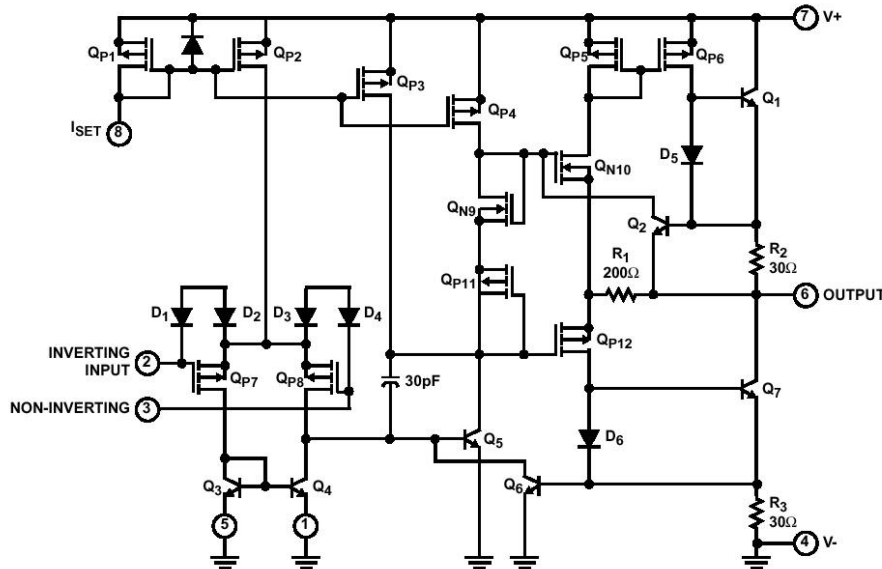


Figure 22. Internal circuit structure of CA3440 Low Power Operational Amplifier. Here V_{DD} is labeled as V_+ and V_{SS} is labeled as V_- .

NON-IDEAL OPERATIONAL AMPLIFIERS

- We will examine the operation of an amplifier system, using the model for an actual Operational Amplifier, the National Semiconductor LM324. This is one of the supplied devices in the EVAL parts library for your PSpice edition.
- This will be a Unity Gain amplifier with supply bias values of $V_{DD} = +5V$ and $V_{SS} = -5V$.

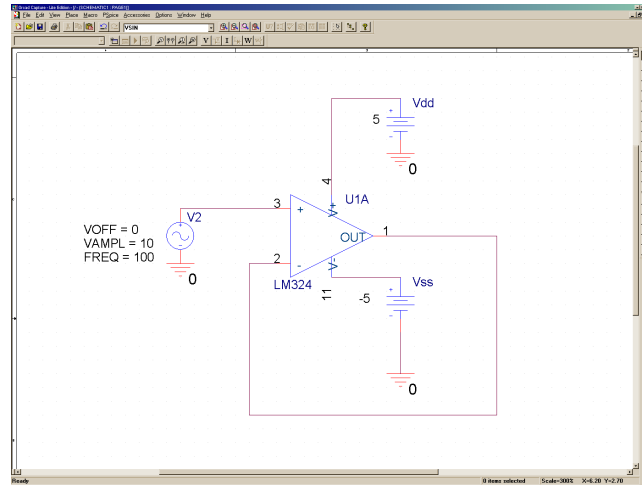


Figure 23. Unity Gain amplifier implemented with an LM324. Note supply bias values are $V_{DD} = +5V$ and $V_{SS} = -5V$.

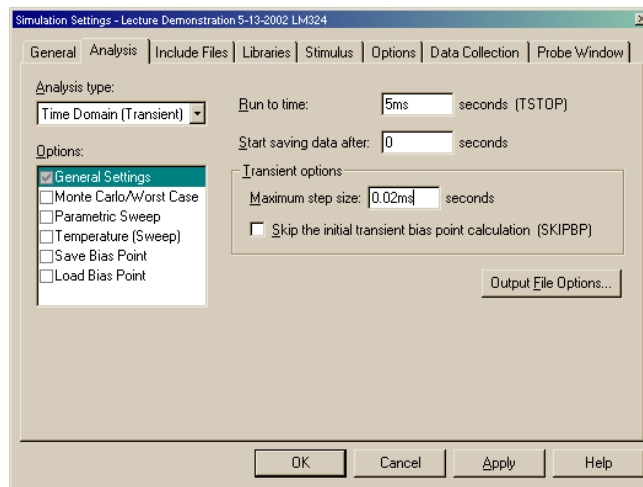


Figure 24. We will be using Transient Analysis - this is the Simulation Profile.

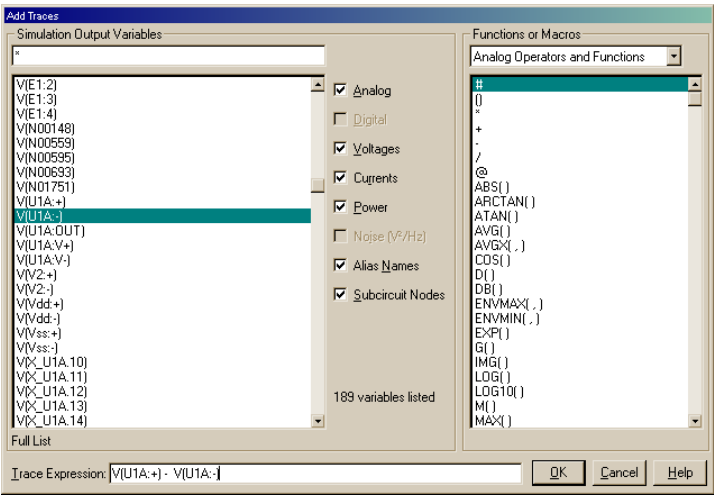


Figure 25. We will view our circuit output over a period of time. We will be plotting "traces" with the PSpice simulator. Here, we are "Adding" a Trace corresponding to a difference between input voltages for our Amplifier.

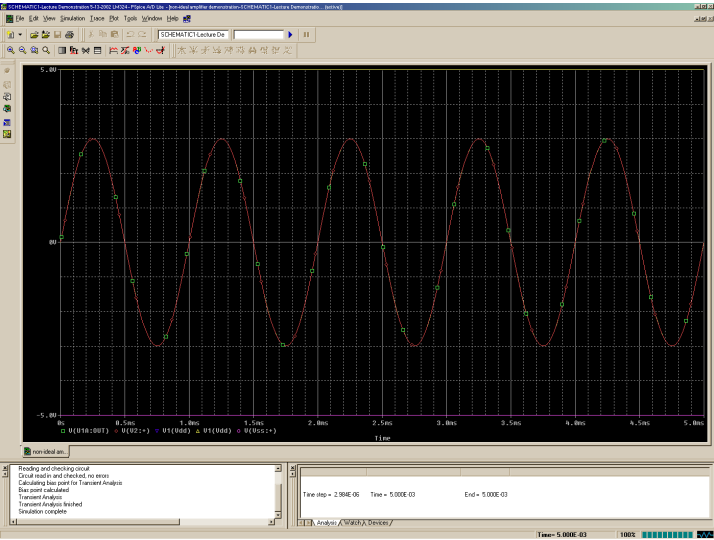


Figure 26. Output voltage for a condition of input voltage amplitude equal to 3V. This corresponds to a 1 kHz sine wave. Both input and output signals are plotted. They are indistinguishable here – as expected.

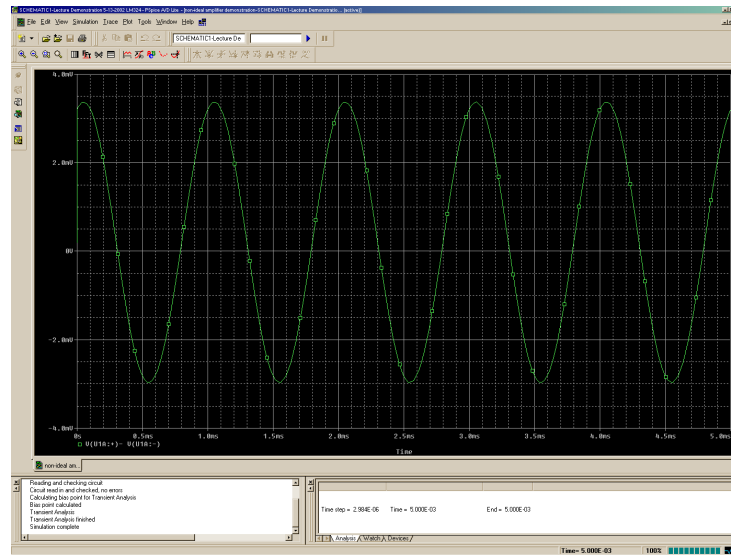


Figure 27. This Trace displays the voltage difference between the Amplifier inputs for a 3V input amplitude. Note the low value of this signal difference.

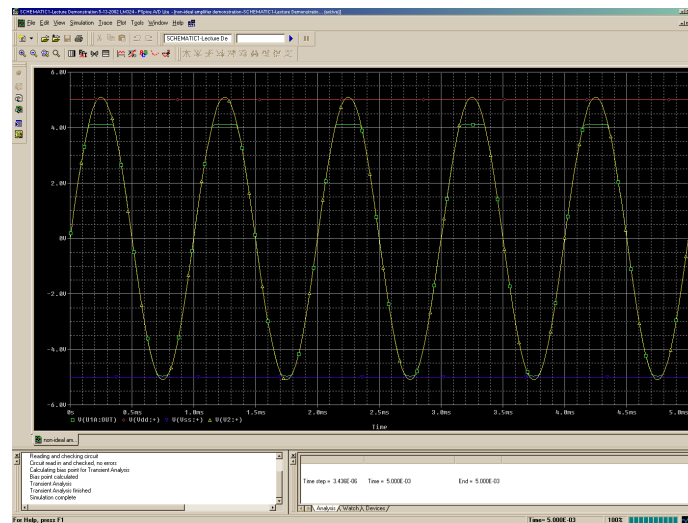


Figure 28. Output voltage for the case of an input voltage amplitude of 5.1V. Note the saturation behavior.

- It is very important for us to stop here and discuss the intuition required to understand this.

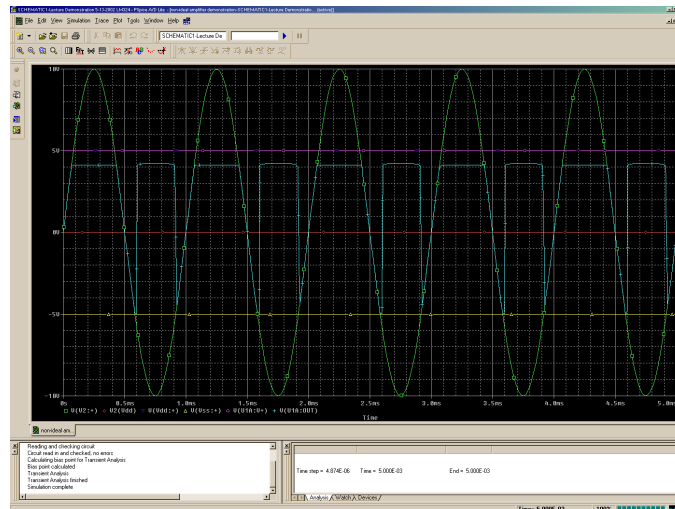


Figure 29. Output voltage for the case of an input voltage amplitude of $5.1V$. Note the extreme non-linear behavior.

OPERATIONAL AMPLIFIER APPLICATIONS: FREQUENCY-SELECTIVE FILTER

- PSpice and other Computer Aided Design tools also offer methods for analyzing the properties regarding the frequency dependence of circuits and systems.
- In this case, the PSpice system “sweeps” the signal frequency of a source over a frequency range, while computing circuit behavior.
- This is demonstrated here for an Operational Amplifier filter circuit.

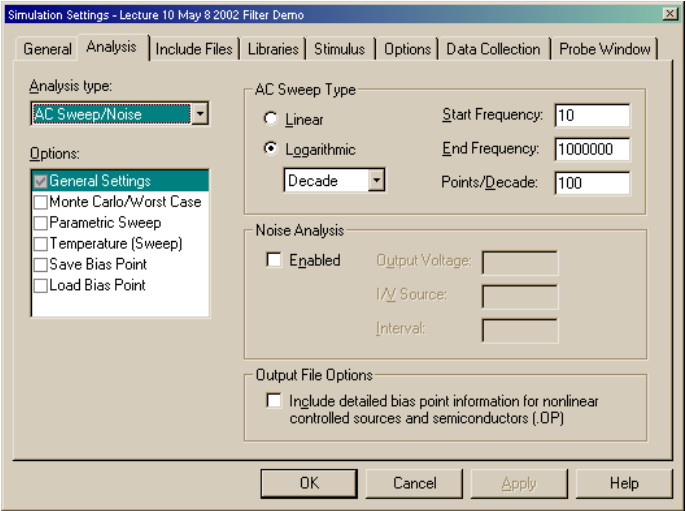


Figure 30. The profile used for "AC" analysis

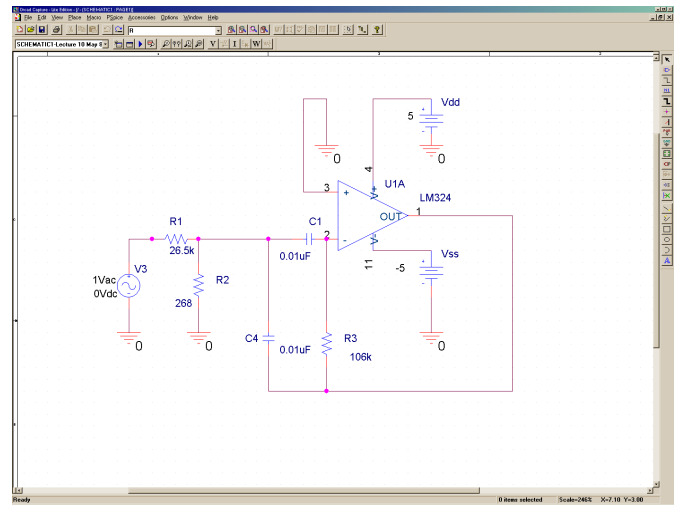


Figure 31. The Filter circuit

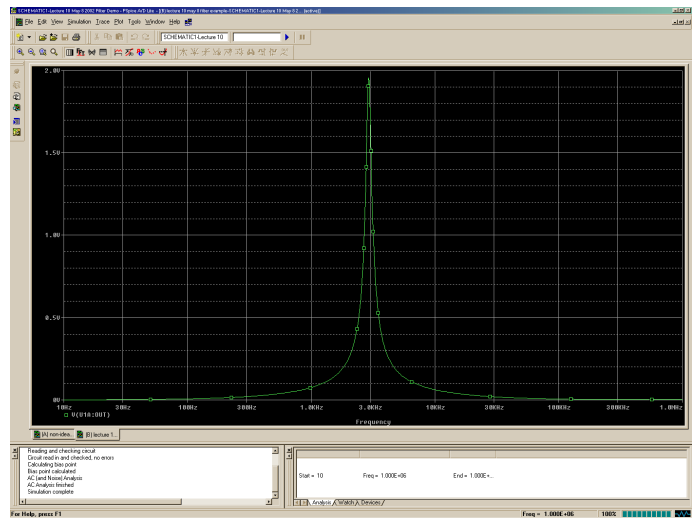


Figure 32. The Filter response

IDEAL OPERATIONAL AMPLIFIER CIRCUIT

- Next steps:
- We will analyze the following systems:
- Inverting Voltage Amplifier
- Inverting Current Amplifier
- Differential Voltage Amplifier
- We will be examining properties including voltage gain and input and output resistance values.
- We will be performing PSpice simulations as well