

Applications of Dependent Sources:

Dependent sources provide a convenient means of:

1. converting between voltage and current
2. changing resistance

Since dependent sources often appear in the part of the circuit that we are using to make a measurement, they also enable the input and output characteristics of a device to be optimized separately.

Look at the amplifier circuit shown on Figure 1.

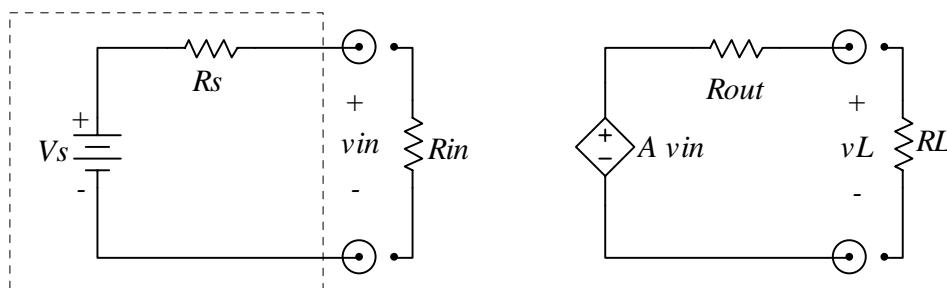


Figure 1. Amplifier circuit

The circuit at the far left is a Thevenin equivalent of a voltage source. So this can stand in place of any voltage source regardless of the actual complexity of the physical source. The resistor R_{in} is used to measure the voltage v_{in} that is provided by this source. Since R_{in} is the basis of a voltage measurement we desire that $R_{in} \gg R_s$. This is a general design criterion that we have seen before.

The circuit at the right is a Thevenin equivalent voltage source driving a load. Here the good design characteristics require that $R_{out} \ll R_L$.

By breaking the circuit into four components as shown on Figure 2 we will be able to investigate the details of each part for a deeper understanding.

We are particularly interested to determine the relation between the input signal V_s and the output voltage or current.

The amplifier part of the circuit consists of the measurement part and the output equivalent circuit.

By describing the circuit in terms of the Thevenin equivalent circuits we have provided

the most compact form possible for this application. As always the i - v characteristic plots of the input and the output sides of the circuit, as shown on Figure 3, provide additional insight.

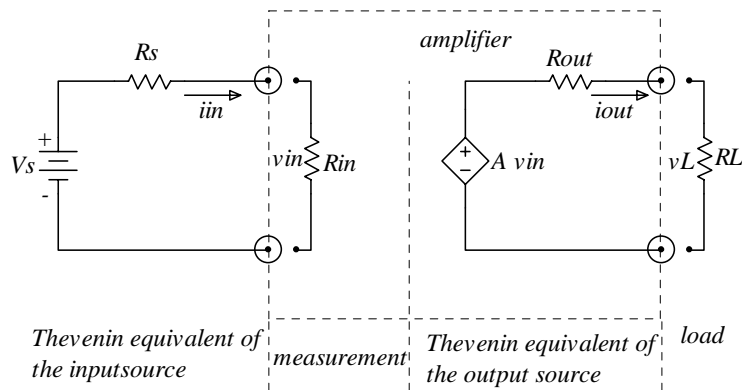


Figure 2. Detailed breakdown of the amplifier circuit

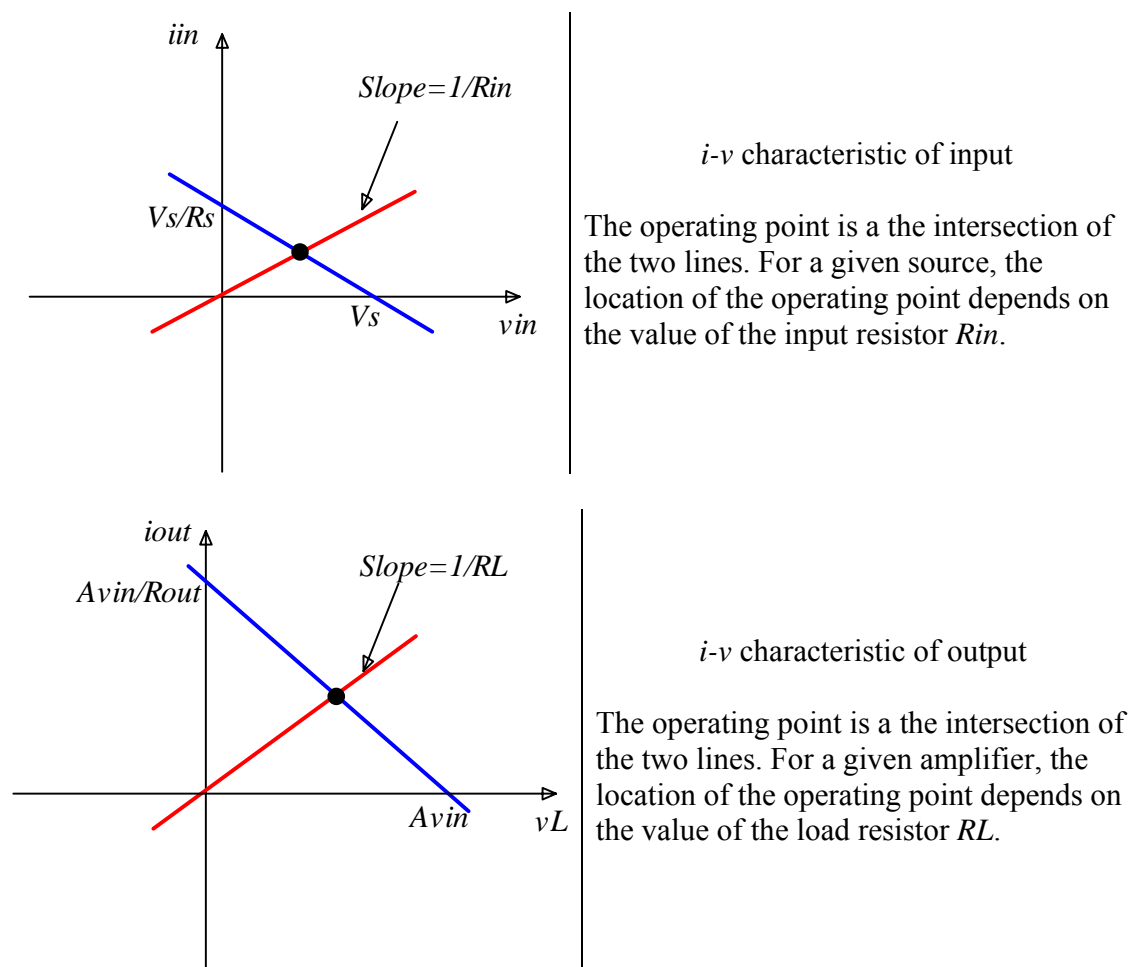


Figure 3. i - v plots of input and output circuits of an amplifier

Here then we see that depending on the choice of the resistors and the parameter A we can build an amplifier that detects a voltage and delivers power. Notice that V_s would often be a time varying voltage (a signal) and so the operating points would slide back and forth, but the slopes would not change.

Change of Resistance¹

Let's look at the amplifier section of the circuit shown on Figure 2 when $A=1$. This circuit is shown on Figure 4. Since $A=1$, the circuit does not provide any voltage gain. So what is the purpose of this amplifier?

The answer becomes obvious when we look at the power transfer characteristics of the circuit.

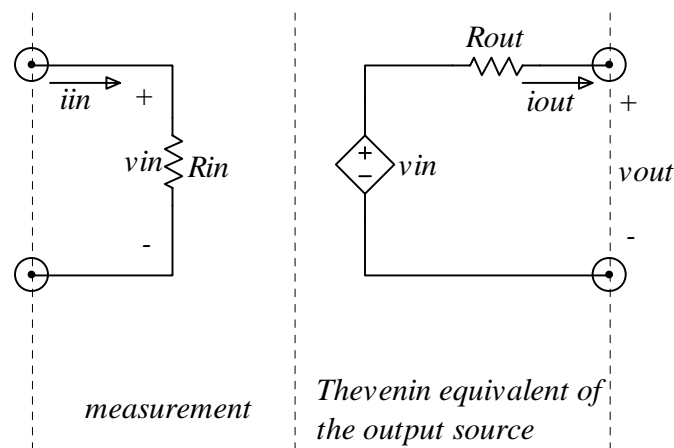


Figure 4. Power amplifier circuit

The power at the input side of the amplifier is

$$P_{in} = \frac{v_{in}^2}{R_{in}} \quad (0.1)$$

And the power at the output is

$$P_{out} = \frac{v_{in}^2}{R_{out}} \quad (0.2)$$

And thus the gain in power is

¹ This change in resistance is often called change in impedance. Impedance is a generalized resistance that we will see much more of when we turn to reactive elements (capacitors and inductors). For now we will equate it to the characteristic (Thevenin or Norton) resistance of a port.

$$\frac{P_{out}}{P_{in}} = \frac{R_{in}}{R_{out}} \quad (0.3)$$

It is a common situation, to have the input resistance high (so that we are effectively measuring a voltage), and the output resistance low (so that we are effectively providing a power).

Decibels

The decibel is used to measure the ratio of two powers or equivalently the gain in power. The gain in decibels is given by

$$gain(dB) = 10 \log_{10} \frac{P_{out}}{P_{in}} \quad (0.4)$$

For an amplifier system as shown on Figure 5, the gain may also be written in terms of the input and output voltage or current.

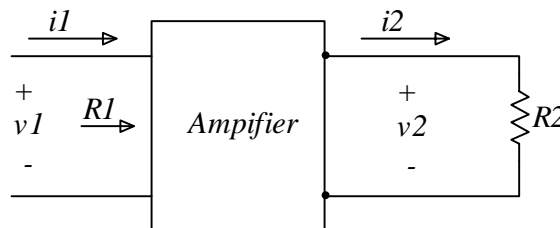


Figure 5 Amplifier system

$$\begin{aligned} gain(dB) &= 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{v_2^2 / R_2}{v_1^2 / R_1} \\ &= 10 \log_{10} \left(\frac{v_2}{v_1} \right)^2 - 10 \log_{10} \frac{R_2}{R_1} \end{aligned} \quad (0.5)$$

Notice that if the input and output resistances are the same, ($R_1=R_2$) then the gain can be rewritten in terms of voltage,

$$gain(dB) = 20 \log_{10} \frac{v_2}{v_1} \quad (0.6)$$

Or the current

$$gain(dB) = 20 \log_{10} \frac{i_2}{i_1} \quad (0.7)$$

Use of Dependent Sources

Let's consider the voltage controlled voltage source shown on Figure 6

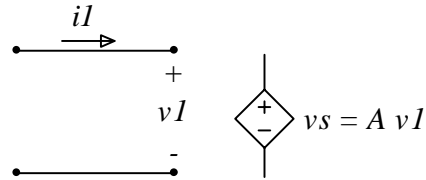


Figure 6. VCVS

In practice these devices are made to have a very large but imprecise gain A . The variability in the value of A from device to device and due to various environmental condition (change in the operating temperature for example) results in undesirable effects.

In order for these devices to be useful they must be arranged in a circuit in such a way that the actual value of the gain A does not affect the operation of the circuit. In practice this is achieved with feedback, resulting in a smaller overall, but precise, gain, and a stable operating condition

We will explore many applications of this in the near future, here we just give a first exploratory example. Consider the circuit shown on Figure 7.

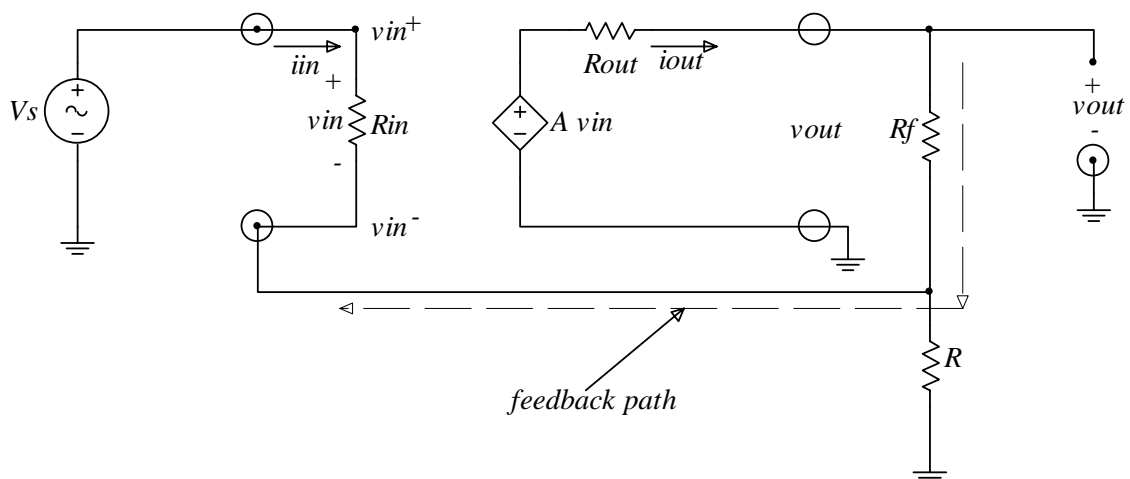


Figure 7. Amplifier with feedback

The feedback path is indicated by the dashed line on Figure 7. As we will see next by analyzing the circuit, the *feedback* is used to set the gain of the amplifier. Notice that the feedback path *samples the output* and delivers this to the *negative* terminal of the input. This is an example of negative feedback.

Let's make three assumptions related to the quality of the input and output parts of the amplifier.

1. assume that A is very large (typically $A \sim 500,000$),
2. assume that R_{out} is small (a few Ω)
3. R_{in} is very large ($\sim M\Omega$)

Together the above assumptions mean that the output stage has high gain and can deliver power, and that the input stage has no influence on the measurement of the output voltage.

The key to this type of "negative" feedback is to investigate the voltage at the negative terminal of the input,

$$v_{in}^- = v_{out} \frac{R}{R_f + R} \quad (0.8)$$

since

$$v_{in}^+ = V_s \quad (0.9)$$

And

$$A v_{in} = A(v_{in}^+ - v_{in}^-) = v_{out} \quad (0.10)$$

v_{out} becomes

$$v_{out} = A \left(V_s - \left(\frac{R}{R + R_f} \right) v_{out} \right) \quad (0.11)$$

And the voltage gain of the circuit is

$$\frac{v_{out}}{V_s} = \frac{A}{1 + \frac{R A}{R + R_f}} \quad (0.12)$$

And since the parameter A is very large, Equation (0.12) reduces to

$$\frac{v_{out}}{V_s} \approx \frac{R + R_f}{R} \quad (0.13)$$

So we see that by using feedback we have made an amplifier whose voltage gain is independent of the internal gain of the device (A).

Since the input resistor R_{in} is very large, the amount of current flowing through it is very small (we will assume that it is zero). Therefore, the current flowing through resistor R is given by

$$i = \frac{v_{out}}{R + R_f} \quad (0.14)$$

By substituting Equation (0.13) into Equation (0.14) the current is given by

$$i = \frac{V_s}{R} \quad (0.15)$$

And so we see that the current flowing through resistor R does not depend on the value of the feedback resistor R_f . The amount of current flowing through R_f is determined by the value of resistor R and the input voltage V_s .

We have thus designed a device that can provide a specified amount of current: A **Current Source**. The dashed rectangle on Figure 8 designates the current source device.

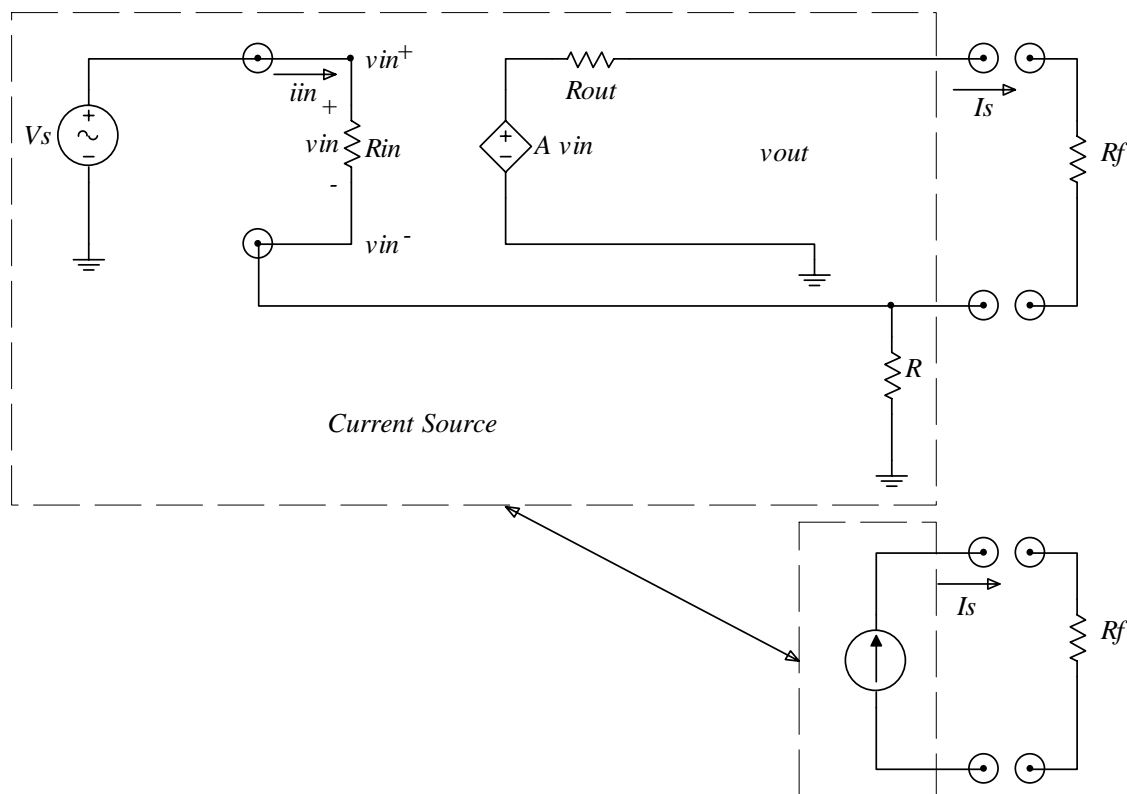
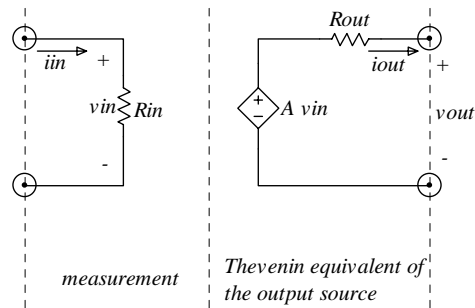


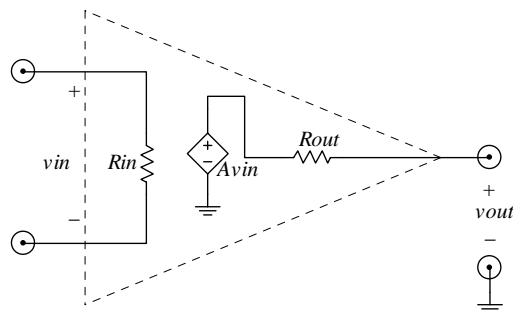
Figure 8. General schematic of current source constructed with a dependent voltage source.

We will construct this device and investigate its behavior and characteristics in the laboratory. For the dependent source we will use a component called the operational

amplifier which is a voltage controlled voltage source (VCVS). The schematic diagram of the operational amplifier is shown on Figure 9.



(a)



(b)

Figure 9. Amplifier circuits. (a) original circuit with dependent source, (b) same circuit enclosed by the operational amplifier triangle symbol.

The operational amplifier symbol is shown on Figure 10. The operational amplifier is a 5-terminal active device. We will explore it in great detail later in the term. For now we will investigate its general operational characteristics without consideration of its detailed attributes.

The two terminals labeled V_{DD} and V_{SS} are the positive and negative power supply connections. Since this is an active device since this is an active device. It requires an external power supply since it can deliver a gain of greater than 1 (or 0 dB).

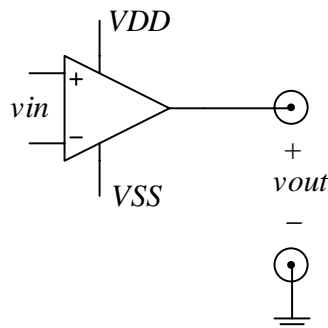


Figure 10. Operational amplifier symbol.