Purpose:

The objective of this experiment is to compare and contrast the four circuit models for an amplifier provided in Figure 1 using an operational amplifier circuit.

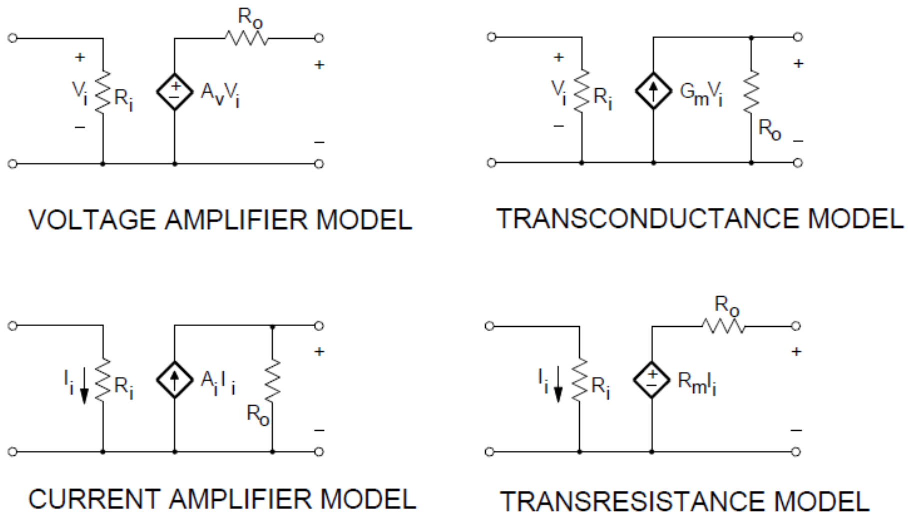

Figure 1. Four possible amplifier circuit models.
In this diagram, $A_v = V_o/V_i$, $G_m = A_v/R_o$, $A_i = A_vR_i/R_o$, $R_m = A_vR_i$.

Equipment:

LM741 operational amplifier
Resistors: R_1, R_2, R_3
Capacitors: C_1, C_2 (each 1 μF)
Resistive decade box: HeathKit IN-3117

Power supply: HP E3631A
Multi-meter: Fluke 8010A (x2)
Function generator: HP 33120A
Oscilloscope: Agilent 54622D

Procedure:

One particular op-amp circuit was studied: an inverting amplifier, constructed according to the schematic of Figure 2. According to circuit analysis of this op-amp configuration, to achieve a voltage gain of approximately $A_v = -10$ with $R_2 = 10$ kΩ, the values of resistors R_1 and R_3 are both approximately 1 kΩ. The positive 15-V supply was fed to the LM741 op-amp from the +25-V output of the HP E3631A. The negative 15-V supply was fed to the op-amp from the –25-V output of the same E3631A. Capacitors C_1 and C_2 were placed between ground and the negative and positive power rails, respectively.

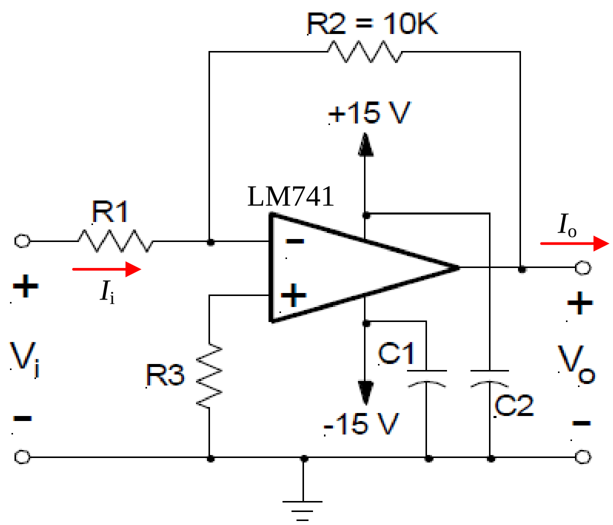

Figure 2. Schematic of an inverting amplifier which uses the LM741 op-amp.

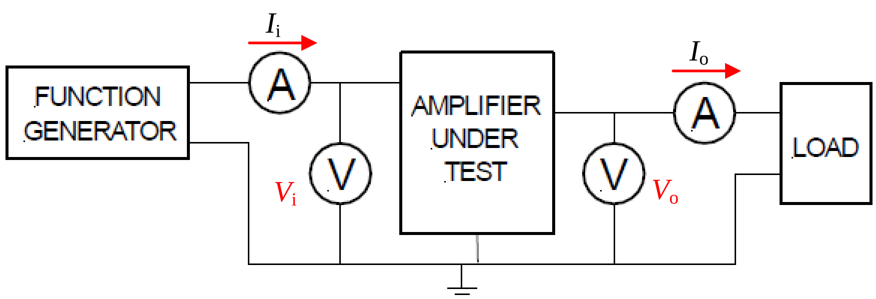

Figure 3. Test configuration for measuring the input current (I_i), input voltage (V_i), output current (I_o), and output voltage (V_o) from the op-amp circuit.

The values of resistors R_1–R_3 were measured using the ohm-meter setting on a Fluke 8010A to determine the deviation from their nominal values. The nominal and measured values are given in Table 1, along with percent deviation from nominal. Each resistor was found to be within 1.50% deviation of its nominal value; all were appropriate for constructing the amplifier circuit.

	Nominal *R*	**Measured *R***	**% Deviation**
R_1	1.000 kΩ	0.990 kΩ	1.00 %
R_2	10.000 kΩ	10.150 kΩ	1.50 %
R_3	1.000 kΩ	0.995 kΩ	0.50 %

Table 1. Nominal vs. measured resistance values.

A sine wave at a frequency of 1 kHz and amplitude of approximately 200 mV RMS was applied to the op-amp circuit with the HP 33120A function generator. As seen in Figure 3, the input current I_i was measured between the function generator and the op-amp circuit with a Fluke 8010A set to measure AC RMS current. The input voltage V_i was measured at the input to the op-amp circuit (beyond the first ammeter) using Channel 1 of the Agilent 54622D oscilloscope and the V-RMS measurement setting. The output voltage V_o was measured at the output of the op-amp (before the second ammeter) using Channel 2 of the same oscilloscope and the same measurement setting. The output current I_o was measured between the op-amp circuit and the load using another Fluke 8010A set to measure AC RMS current.

Initially, the four voltages and currents were recorded with an open-circuit load. The experiment was repeated and the four voltages and currents were recorded with a 200-Ω load, the HeathKit IN-3117 set to 2x100 Ω. The unloaded (open-circuit) and loaded (200 Ω) voltage and current values are listed in Table 2.

	No load	**200-Ω load**
$\boldsymbol{V_i}$	200 mV	200 mV
$\boldsymbol{V_o}$	2.040 V	2.020 V
$\boldsymbol{I_i}$	200 μA	200 μA
$\boldsymbol{I_o}$	0 mA	10 mA

Table 2. Input/output voltage/current for op-amp circuit, no load vs. 200-Ω load.

The amplifier parameters R_i (input resistance), R_o (output resistance), A_v (voltage gain), A_i (current gain), G_m (transconductance), and R_m (transresistance) for the four amplifier models of Figure 1 were computed from the measured data of Table 2 as follows:

$R_i = V_i / I_i = 200\text{ mV} / 200\ \mu\text{A} = 1\text{ k}\Omega$

$R_o = V_o\text{ (200 W)} – V_o\text{ (no load)} / I_o\text{ (200 }\Omega) = 2\ \Omega$

$A_v = V_o / V_i = –2\text{ V} / 0.2\text{ V} = –10$ (negative because of 180° shift from input)

$A_i = I_o\text{ (200 }\Omega) / I_i\text{ (200 }\Omega) = 10\text{ mA} / 200\ \mu\text{A} = 50$

$G_m = A_v / R_o = 10 / 2\ \Omega = 5\text{ S}$

$R_m = V_o / I_i = 2.020\ V / 200\ \mu\text{A} = 10\text{ k}\Omega$

Comparison of Results

In Table 3, the amplifier parameters calculated in the prior section (from experimental results) are compared against the theoretical parameters listed in the caption of Figure 1. It should be noted that the input resistance of the inverting op-amp can be derived from circuit analysis: $R_i = R_1$.

	Theoretical	Experimental	% Deviation
$\boldsymbol{A_v}$	–10.00	–10.20	2.00 %
$\boldsymbol{A_i}$	(undetermined)	50	N/A
$\boldsymbol{R_i}$	1.000 kΩ	1.000 kΩ	0.00 %
$\boldsymbol{R_o}$	0 Ω	2 Ω	N/A
$\boldsymbol{G_m}$	∞	5 S	N/A
$\boldsymbol{R_m}$	10 kΩ	10 kΩ	0.00 %

Table 3. Theoretical vs. experimental amplifier circuit parameters.

For all finite and non-zero theoretical values, the experimental values compare well; all experimental values are within a 2.00% deviation from theory. The output resistance R_o is difficult to determine for the inverting op-amp because it is so low (effectively zero); its measurement requires precise voltage readings that cannot be provided by the 54622D VRMS function. The transconductance G_m is also difficult to measure accurately because its value depends on R_o.

Conclusions

Since the output resistance R_o of the inverting amplifier circuit is very low and since G_m is very high (effectively infinity), the two most appropriate amplifier models for this op-amp circuit are those that are not heavily influenced by R_o and G_m: the voltage amplifier model and the transresistance model. Although both of these models include the parameter R_o, this resistance is in *series* with the loaded output and its contribution to the voltage and current characteristics of the amplifier are negligible, whether the amplifier is loaded or unloaded.

For many op-amp circuits, the amplifier parameter most commonly derived is the voltage gain, A_v. Thus the voltage amplifier appears to be the most appropriate choice of circuit model for the inverting amplifier circuit.