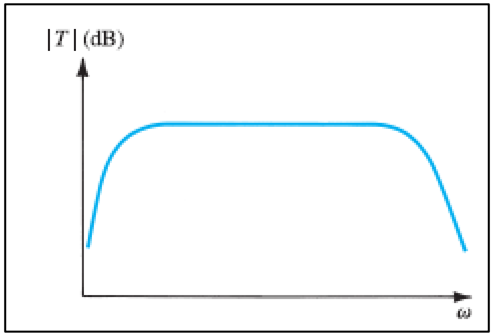
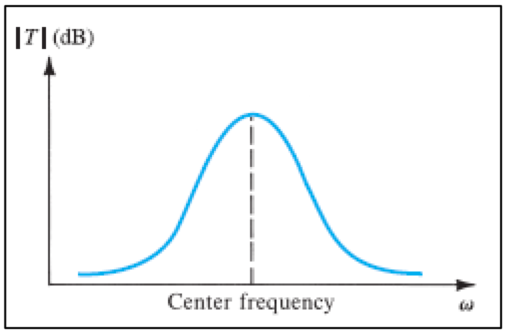
Op Amp Imperfections (Offset Voltage)



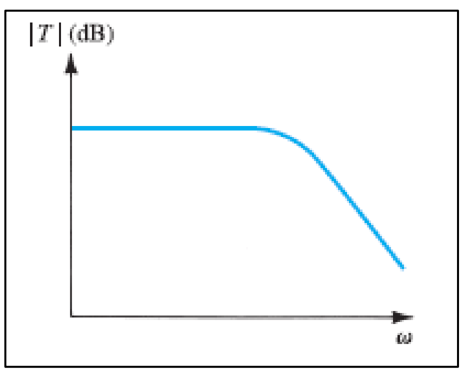
capacitively coupled amplifiers | (ac amplifiers)

Example: audio signal amplifiers.



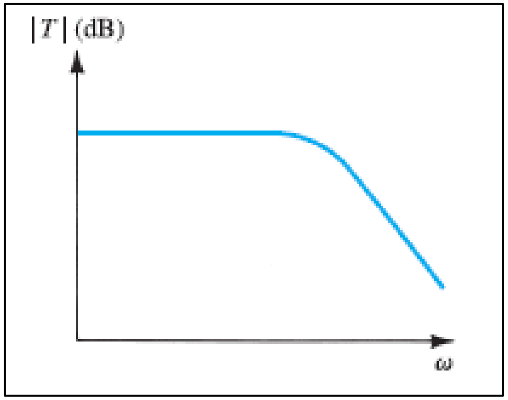
bandpass amplifiers

Example: amplifiers for the design of radio and TV receivers.



direct-coupled amplifiers | (dc amplifiers)

Example: IC amplifiers.



Op amp amplifiers.

direct-coupled amplifiers | (dc amplifiers)

1 Op amps are **direct-coupled devices** with large gains at dc. They are prone to dc problems. **The first such problem is the dc input offset voltage** (V_{OS}) .
The input offset voltage arises as a result of the unavoidable mismatches present in the input differential stage inside the op amp.

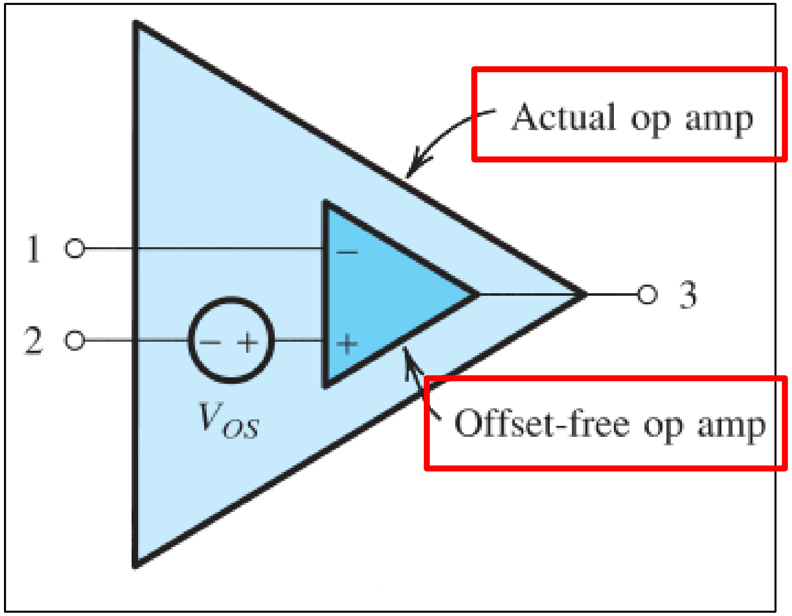
2 If the two input terminals of the op amp are tied together and connected to ground, it will be found that despite the fact that v_{Id} = 0, a finite dc voltage exists at the output.

3 **The op-amp output can be brought back to its ideal value of 0 V by connecting a dc voltage source of appropriate polarity and magnitude between the two input terminals of the op amp.** This external source balances out the input offset voltage of the op amp. **It follows that the input offset voltage must be of equal magnitude and of opposite polarity to the voltage we applied externally**.

4 **The value of V_{OS} depends on temperature. The op amp data sheets usually specify typical and maximum values for V_{OS} at room temperature as well as the temperature coefficient of V_{OS} (usually in μV/°C). General-purpose op amps exhibit V_{OS} in the range of 1 mV to 5 mV.**

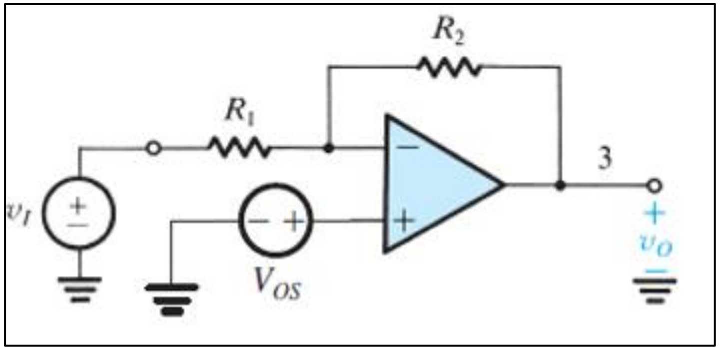
They do not, however, specify the polarity of V_{OS} because the component mismatches that give rise to V_{OS} are obviously not known a priori. **Different units of the same op-amp type may exhibit either a positive or a negative V_{OS}.**

5 To analyze the effect of V_{OS} on the operation of op-amp circuits, we need a circuit model for the op amp with input offset voltage, as shown below.

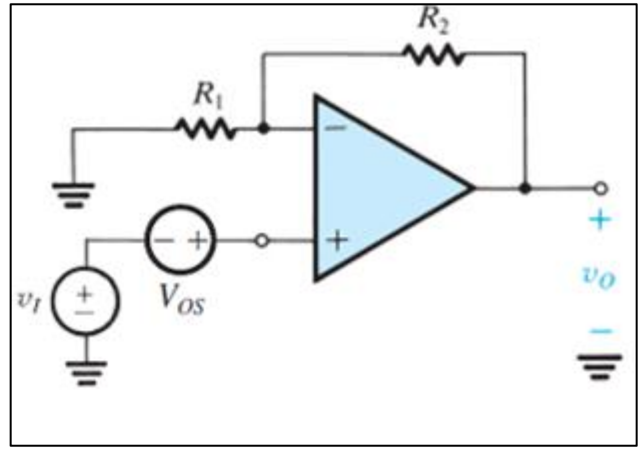


Circuit model for an op amp with an input offset voltage V_{OS}

6

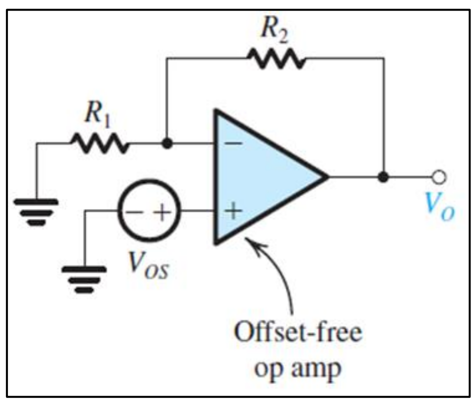


V_{os} model for the Inverter Amplifier



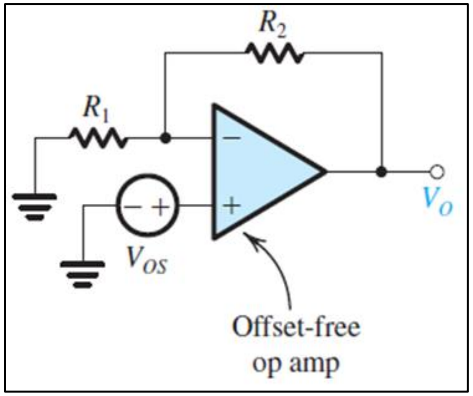
V_{os} model for the Noninverter Amplifier

In both amplifiers grounding the inputs results in a noninverter amplifier with a V_{OS} input .



$$V_o = V_{OS}\left(1 + \frac{R_2}{R_1}\right)$$

7



$$V_o = V_{OS}\left(1 + \frac{R_2}{R_1}\right)$$

This output dc voltage can have a large magnitude.

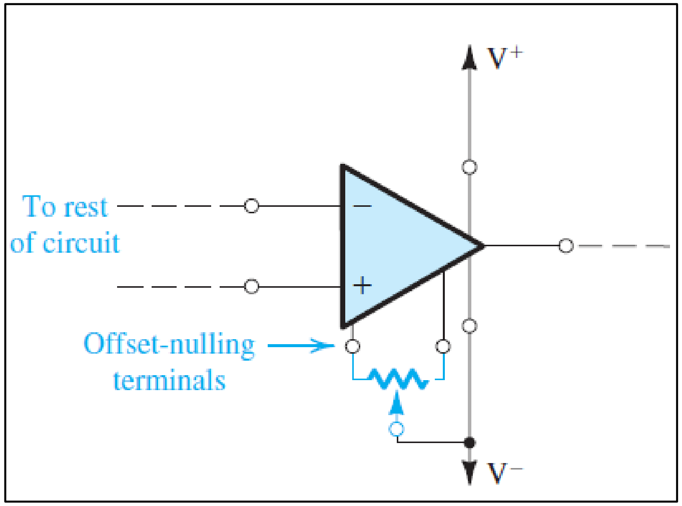
For instance, a noninverting amplifier with a closed-loop gain of 1000, when constructed from an op amp with a 5-mV input offset voltage, will have a dc output voltage of +5 V or −5 V (depending on the polarity of V_{OS}) rather than the ideal value of 0 V.

Now, when an input signal is applied to the amplifier, the corresponding signal output will be superimposed on the 5V dc.

Even worse, if the signal to be amplified is dc, we would not know whether the output is due to V_{OS} or to the signal !

8

Some op amps are provided with two additional terminals to which a specified circuit can be connected to trim to zero the output dc voltage due to V_{OS} . The circuit below shows such an arrangement that is typically used with general-purpose op amps.

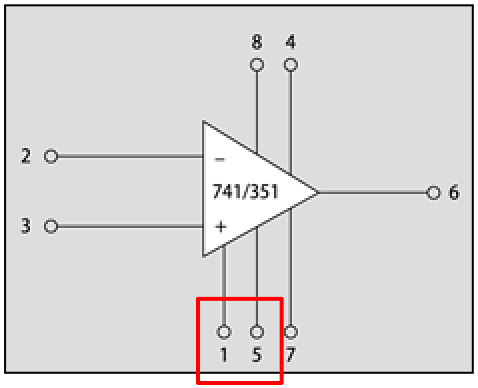


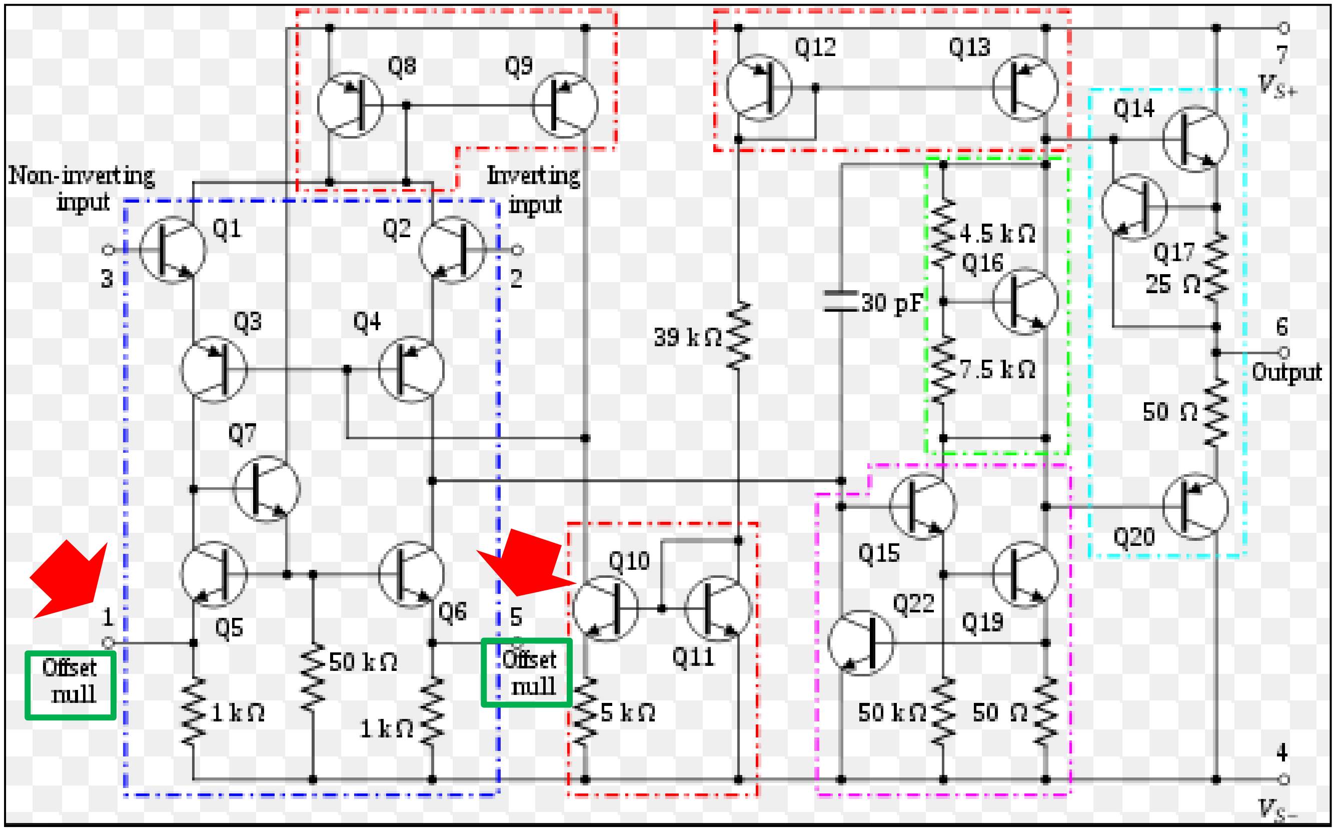
A potentiometer is connected between the offset-nulling terminals with the wiper of the potentiometer connected to the op-amp negative supply. Moving the potentiometer wiper introduces an imbalance that counteracts the asymmetry present in the internal op-amp circuitry and that gives rise to V_{OS}.

It should be noted, however, that even though the dc output offset can be trimmed to zero, the problem remains of the variation (or drift) of V_{OS} with temperature !

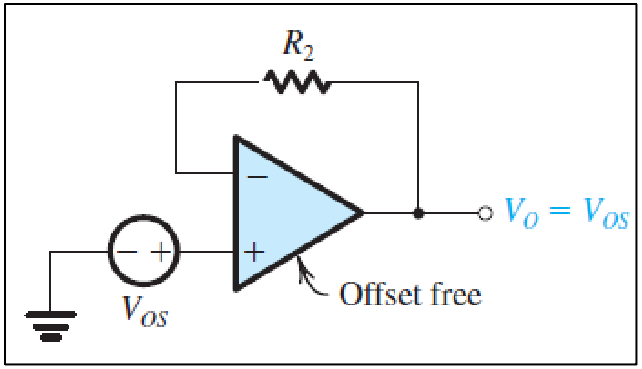
Op Amp 741

Offset Nulling Terminals





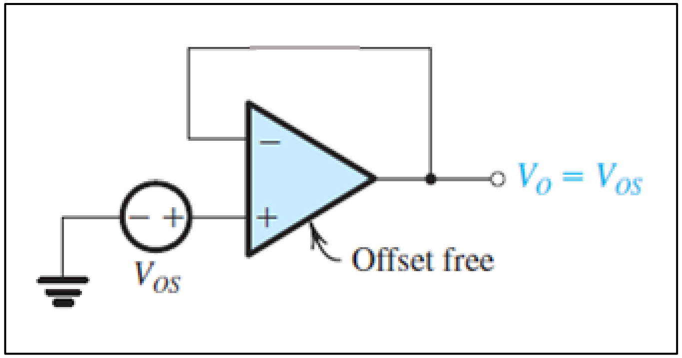
As a result, the equivalent circuit for determining the dc output voltage resulting from the op-amp input offset voltage V_{OS} will be:



$$V_o = V_{OS}\left(1 + \frac{R_2}{R_1}\right)$$

$R_1 = \infty$

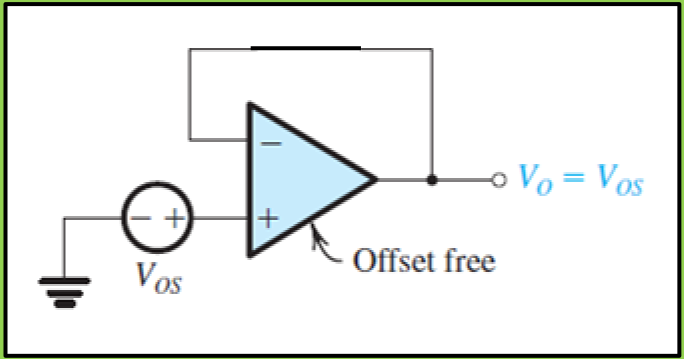
$$V_o = V_{OS}$$



$$V_o = V_{OS}$$

Thus, V_{OS} sees in effect a unity-gain voltage follower, and the dc output voltage V_O will be equal to V_{OS} rather than V_{OS} $(1 + R_2/R_1)$. The R_2 resistance can be replaced by a short circuit.

Measurement of the Offset Voltage in the LTSPice



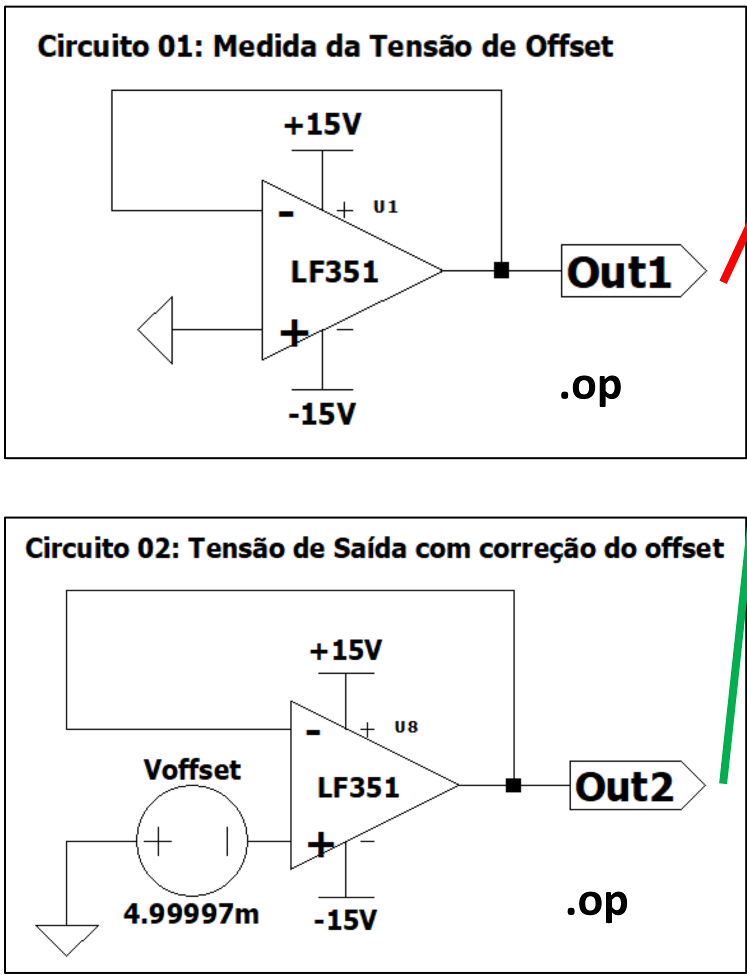
$V_o = V_{OS}$

Input Offset Voltage – Op Amp LF351

The data sheet of the op amp LF351 shows de following information:

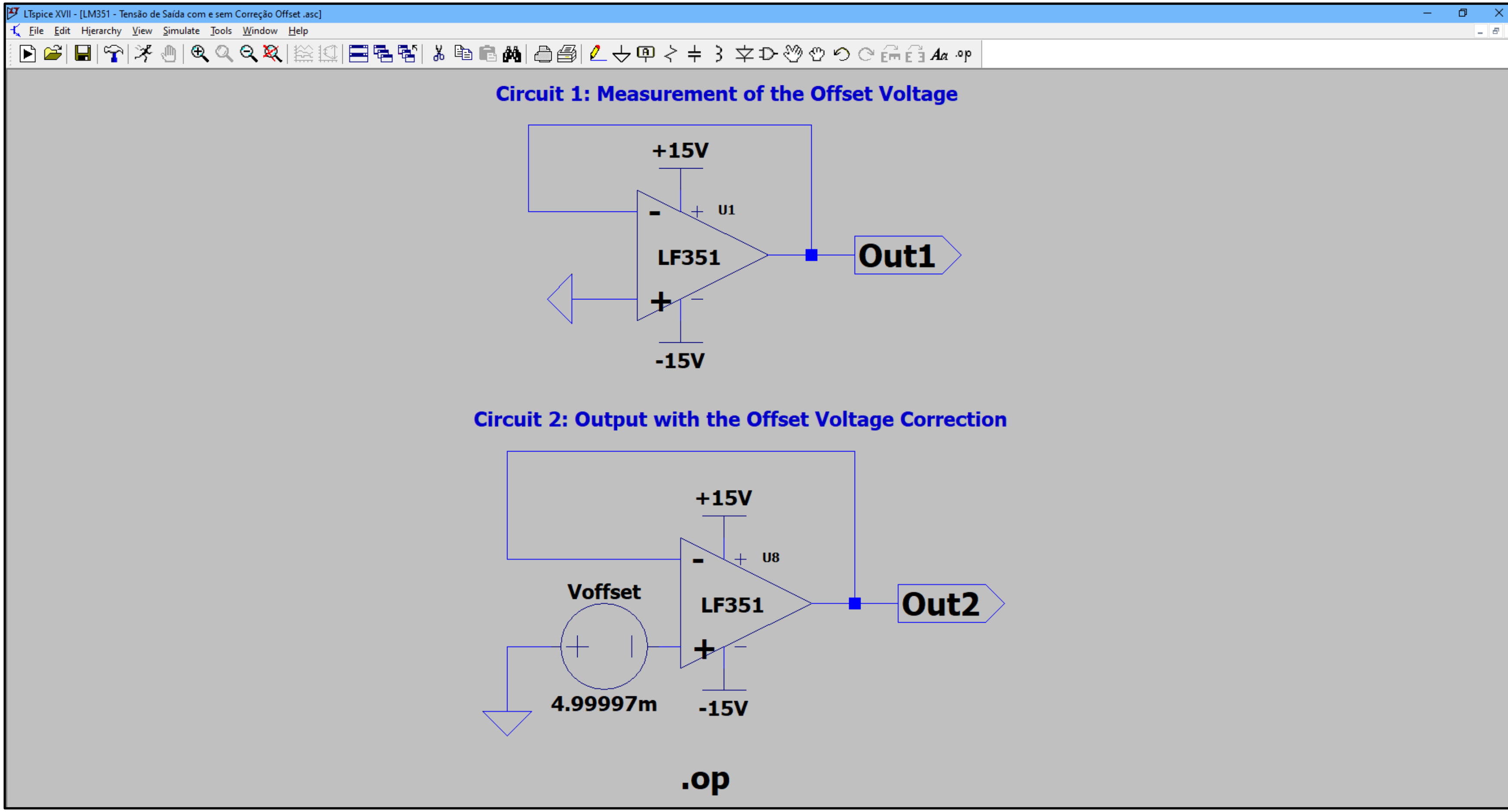
"Input Offset Voltage" (V_{OS} ou V_{IO})	5 mV
Corrente de polarização da entrada ($I_B = \frac{I_p+I_n}{2}$)	50 pA
Offset de corrente da entrada (I_{OS} ou $I_{IO} = I_p - I_n$)	25 pA
Ganho de tensão em malha aberta (A_{VOL})	100 V/mV (100 dB)
"Slew rate" (SR)	13 V/µs
Frequência de Transição (f_T)	4 MHz

The “Input Offset Voltage” can be measured in simulation using a voltage follower circuit with the input grounded, as shown in the figure below. As expected, the output is very close to zero when a DC source with a voltage equal the measured voltage is used in the inverter input.



--- Operating Point ---

V(out1):	0.00499997	voltage
V(n001):	15	voltage
V(n002):	-15	voltage
V(out2):	5.00007e-009	voltage
V(n004):	-0.00499997	voltage
V(n003):	15	voltage
V(n005):	-15	voltage
I(Voffset):	3.89975e-011	device_current
Ix(u1:1):	3.90025e-011	subckt_current
Ix(u1:2):	8.90074e-011	subckt_current
Ix(u1:99):	0.0021	subckt_current
Ix(u1:50):	-0.0021	subckt_current
Ix(u1:28):	-8.90074e-011	subckt_current
Ix(u3:1):	-0.0021	subckt_current
Ix(u5:1):	0.0021	subckt_current
Ix(u8:1):	3.89975e-011	subckt_current
Ix(u8:2):	8.90025e-011	subckt_current
Ix(u8:99):	0.0021	subckt_current
Ix(u8:50):	-0.0021	subckt_current
Ix(u8:28):	-8.90025e-011	subckt_current
Ix(u10:1):	-0.0021	subckt_current
Ix(u12:1):	0.0021	subckt_current

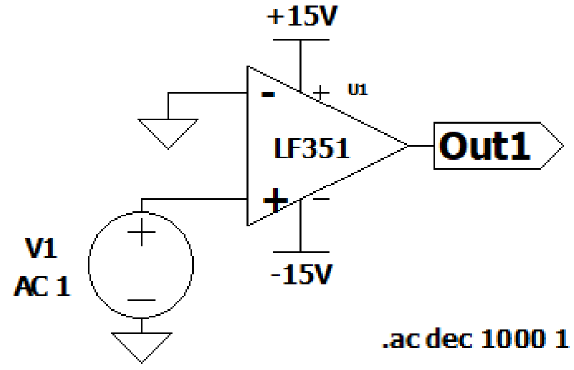

LTspice XVII - [LM351 - Tensão de Saída com e sem Correção Offset .asc]
File Edit Hierarchy View Simulate Tools Window Help
Circuit 1: Measurement of the Offset Voltage
+15V
U1
LF351
Out1
-15V
Circuit 2: Output with the Offset Voltage Correction
+15V
U8
Voffset
LF351
Out2
4.99997m
-15V
.op

It's important to mention that many op amps don't have their performance affected by the offset voltage if it has a very low value (LM741, LM318, TL081, ...) !

Influence of the Input Offset Voltage in the Open Loop Gain

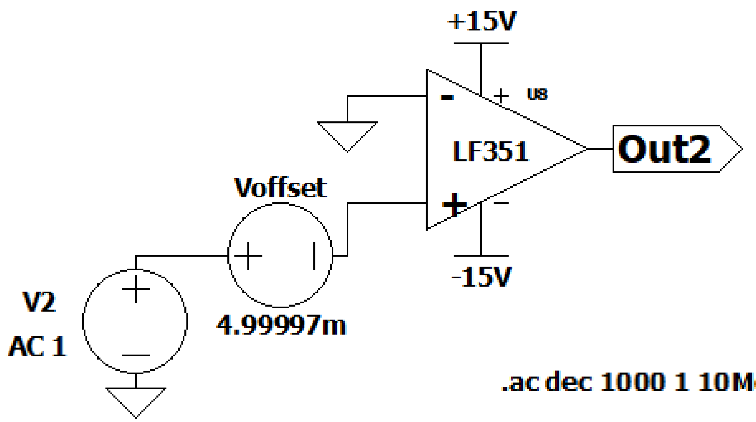
Open Loop Gain

Circuito 1: Ganho de Tensão em Malha Aberta sem correção do offset

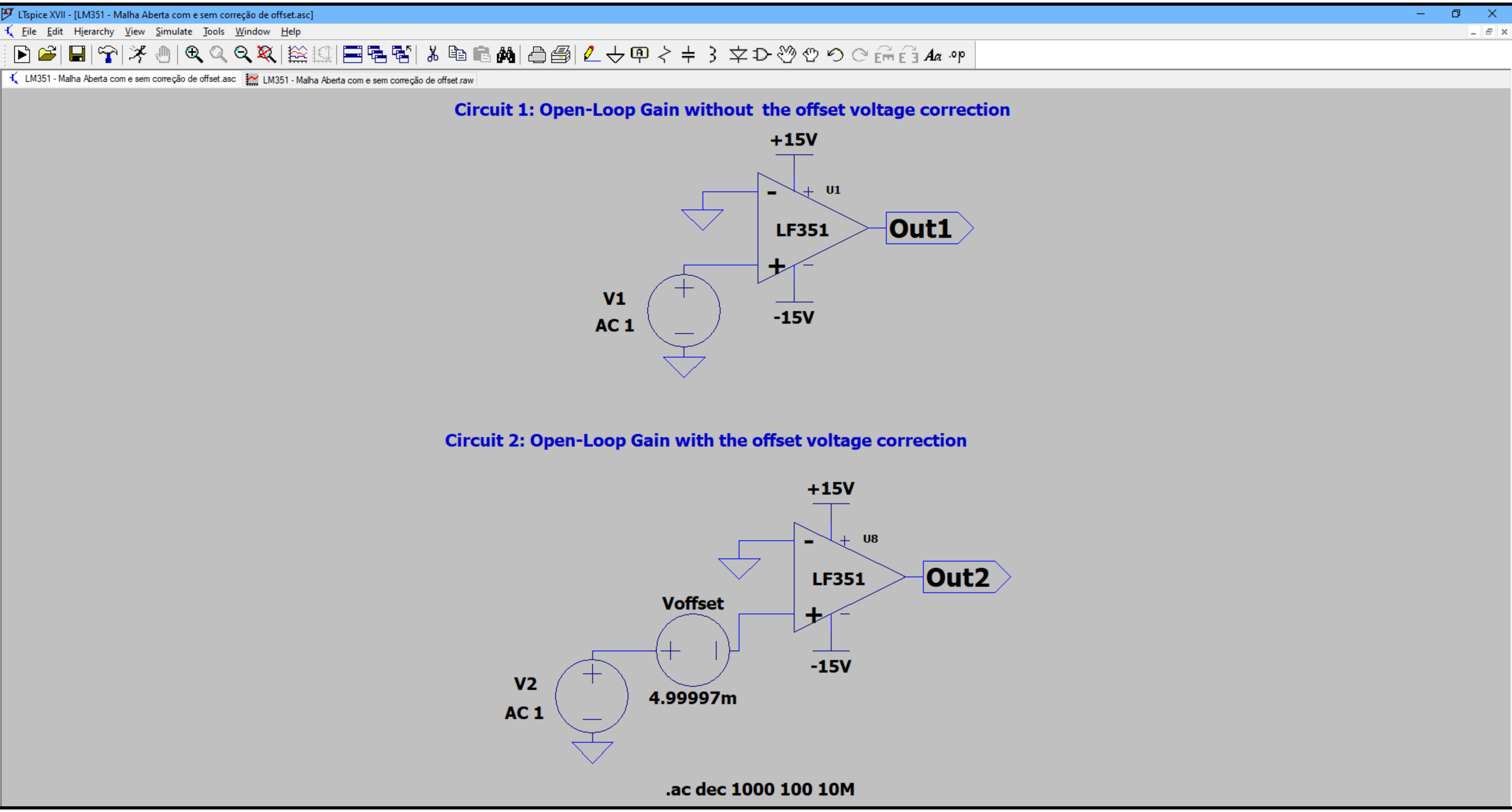


Wrong Result !

Circuito 2: Ganho de Tensão em Malha Aberta com correção do offset

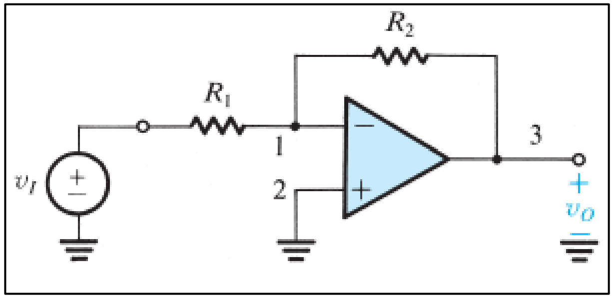


Right Result !

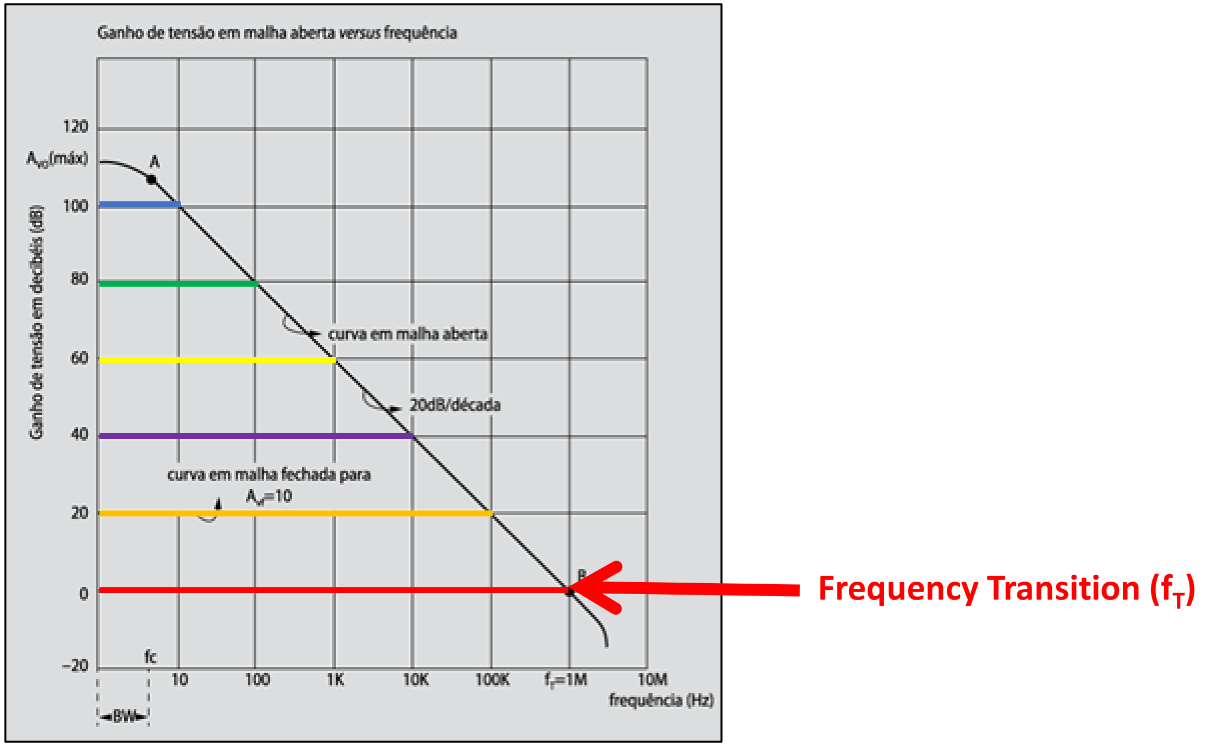


LTspice XVII - [LM351 - Malha Aberta com e sem correção de offset.asc]
File Edit Hierarchy View Simulate Tools Window Help
LM351 - Malha Aberta com e sem correção de offset.asc
LM351 - Malha Aberta com e sem correção de offset.raw
Circuit 1: Open-Loop Gain without the offset voltage correction
+15V
U1
LF351
Out1
V1
AC 1
-15V
Circuit 2: Open-Loop Gain with the offset voltage correction
+15V
U8
LF351
Out2
Voffset
4.99997m
V2
AC 1
-15V
.ac dec 1000 100 10M

Influence of the Input Offset Voltage in the Closed Loop Gain

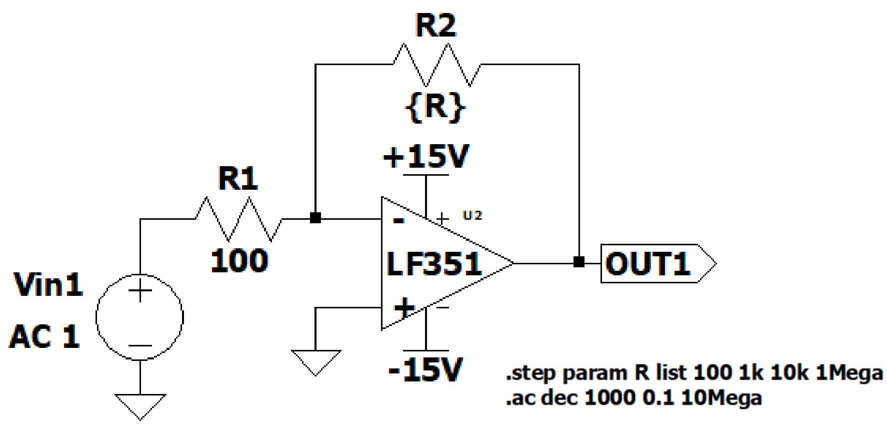

R2
R1
1
2
3
vI
vO

$$G = -\frac{R_2}{R_1}$$


Ganho de tensão em malha aberta versus frequência
Ganho de tensão em decibéis (dB)
120
AV0(máx)
100
80
60
40
20
0
−20
A
B
curva em malha aberta
20dB/década
curva em malha fechada para
AVf=10
fc
BW
10
100
1K
10K
100K
fT=1M
10M
frequência (Hz)
Frequency Transition (fT)

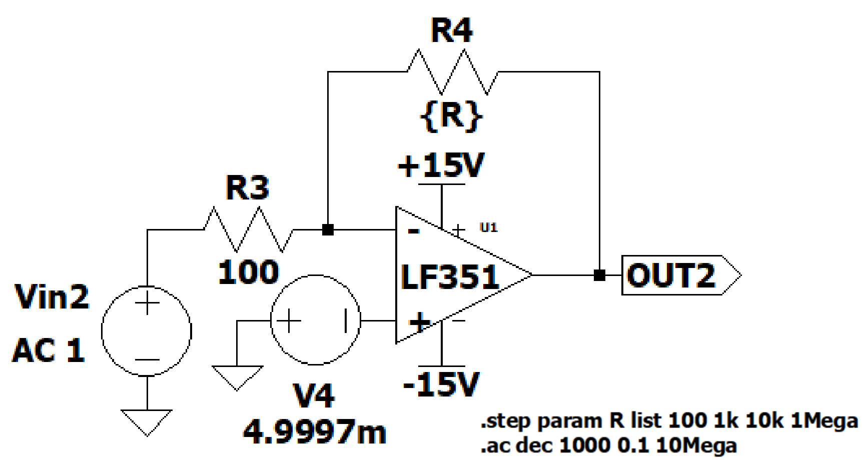
Closed Loop Gain

Circuit 1: Closed gain without the offset voltage correction

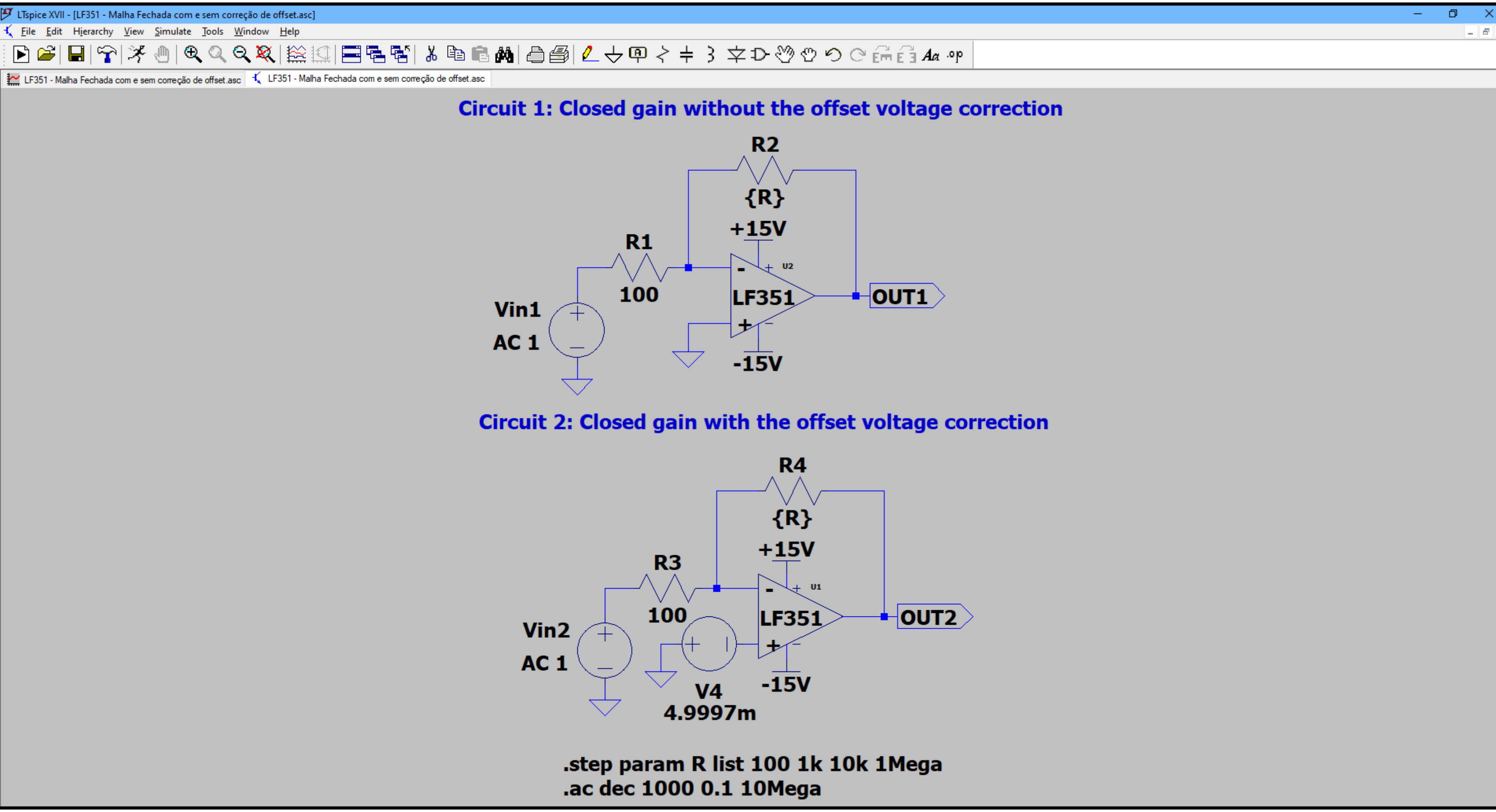


Wrong Result !

Circuit 2: Closed gain with the offset voltage correction



Right Result !


LTspice XVII - [LF351 - Malha Fechada com e sem correção de offset.asc]
File Edit Hierarchy View Simulate Tools Window Help
LF351 - Malha Fechada com e sem correção de offset.asc
LF351 - Malha Fechada com e sem correção de offset.asc
Circuit 1: Closed gain without the offset voltage correction
R2
{R}
+15V
R1
100
U2
LF351
OUT1
Vin1
AC 1
-15V
Circuit 2: Closed gain with the offset voltage correction
R4
{R}
+15V
R3
100
U1
LF351
OUT2
Vin2
AC 1
-15V
V4
4.9997m
.step param R list 100 1k 10k 1Mega
.ac dec 1000 0.1 10Mega

It's important to mention that many op amps don't have their performance affected by the offset voltage if it has a very low value (LM741, LM318, TL081, ...) !