LABORATORY MANUAL
ELECTRONICS LABORATORY II
EE 3709

November 16, 2016

DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING
CALIFORNIA STATE UNIVERSITY, LOS ANGELES

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F8: Cursor Mode in Analysis Window

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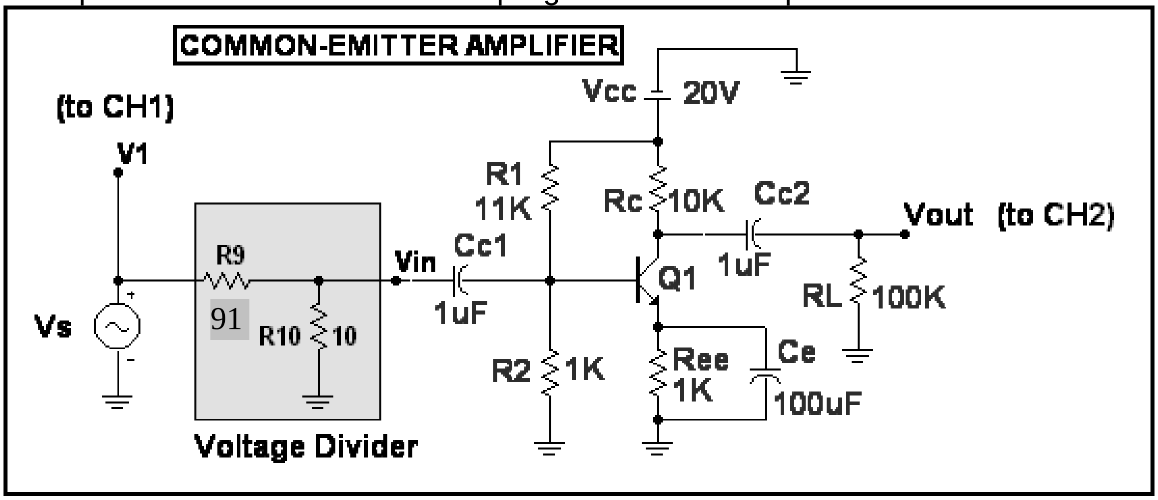
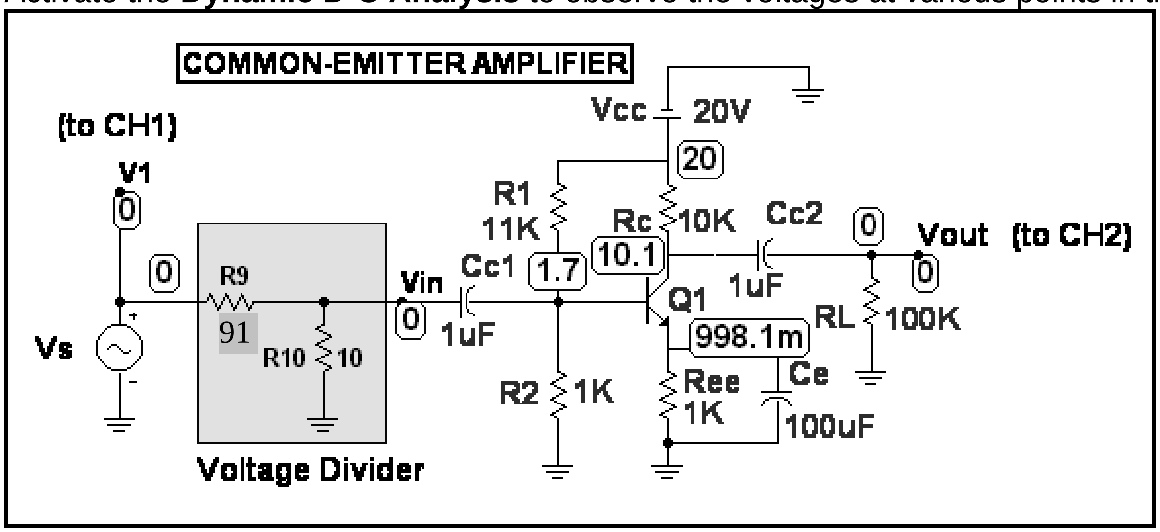
Ctrl + T: Text Mode
Ctrl + W: Straight Wire Mode

Exp 1.1 D-C Voltages

Set up this circuit in the simulation program and on the proto-board.



Activate the **Dynamic D-C Analysis** to observe the voltages at various points in the circuit.

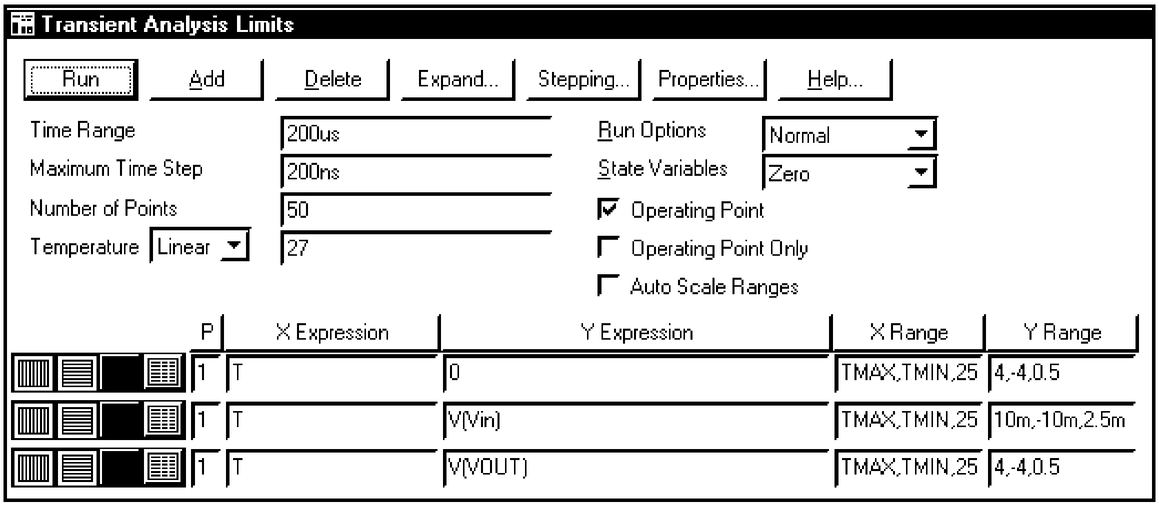


Compare these voltages with the corresponding values measured in the actual circuit.

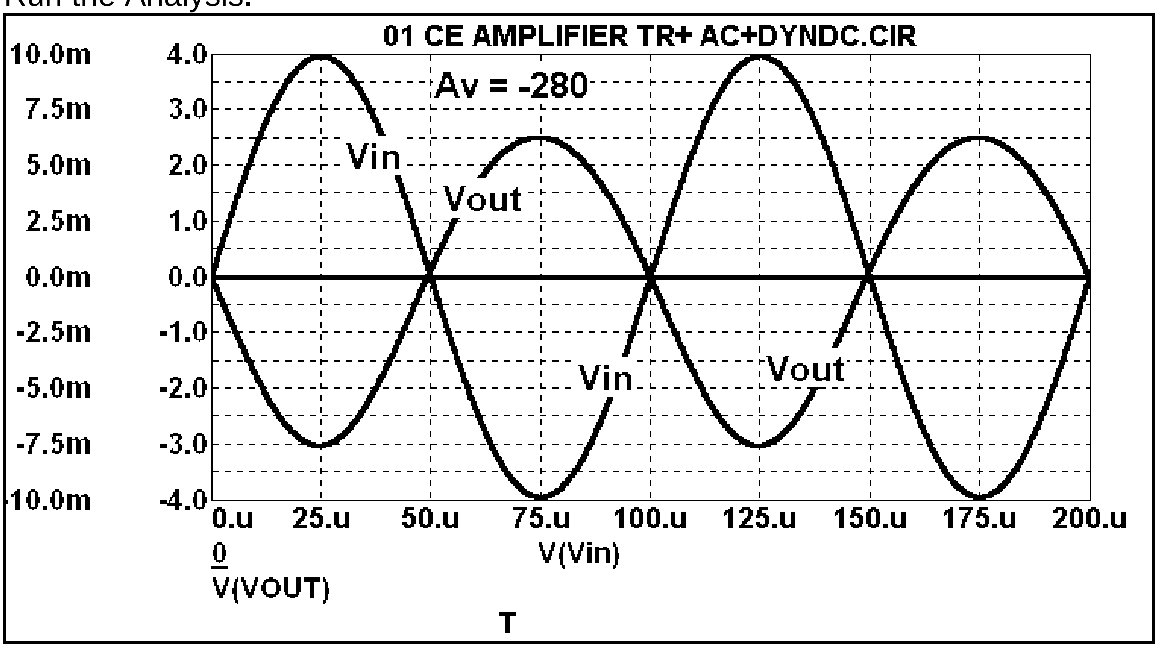
Exp 1.2 Output Voltage and Voltage Gain

Set the signal source to have an amplitude of 100 mV at f = 10 kHz. This will result in Vin having an amplitude of 10 mV due to the 10:1 voltage divider comprised of R_9 and R_{10}.

Use these **Transient Analysis Limits**.



Run the Analysis.

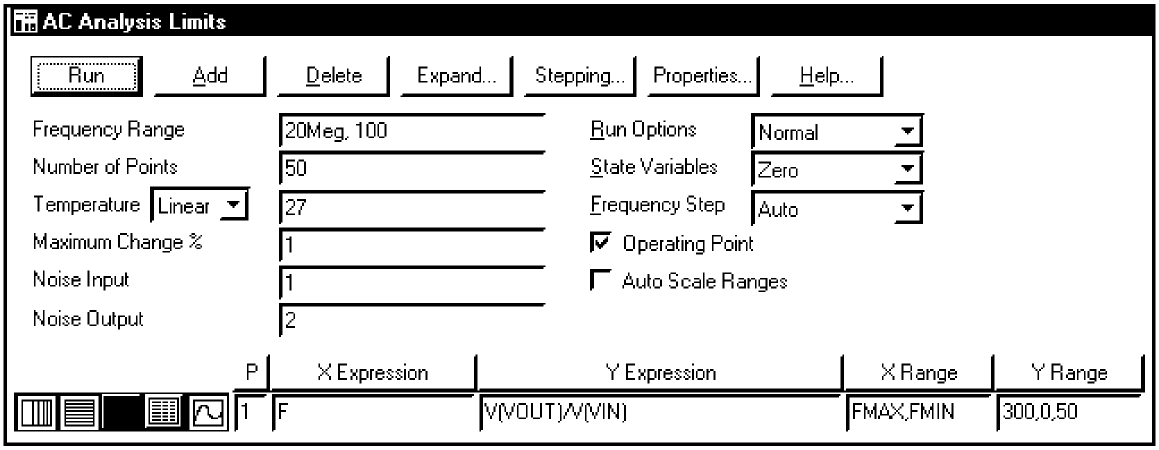


Determine the voltage gain.

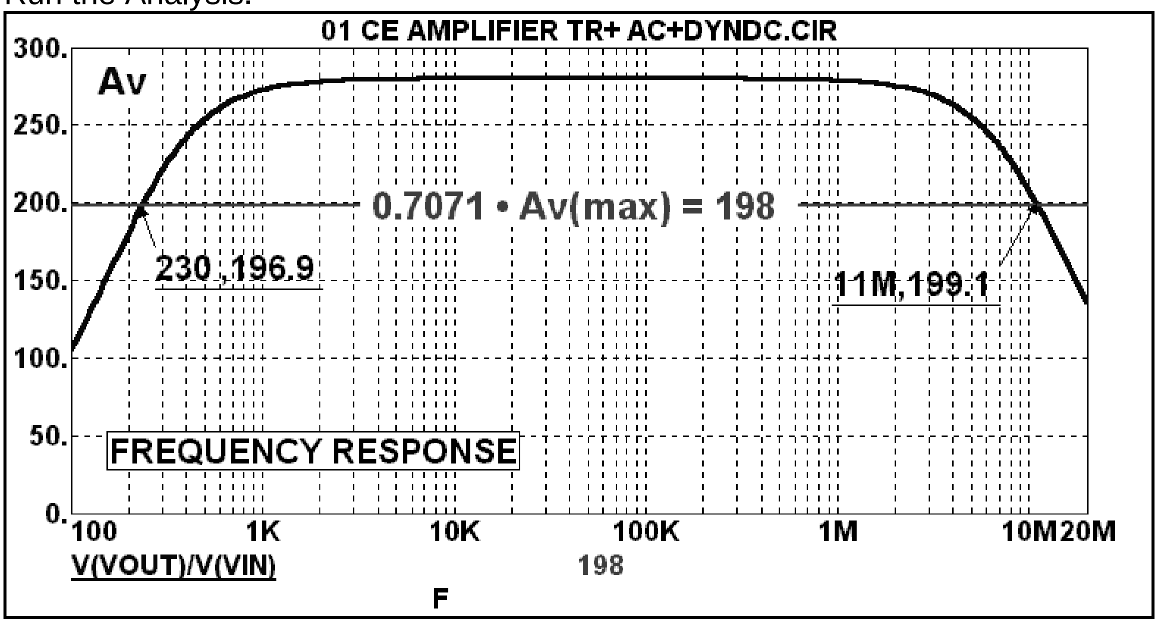
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. Compare the voltage gain of the actual circuit with that of the simulation.

Exp 1.3 Frequency Response

Use these **A-C Analysis Limits**.



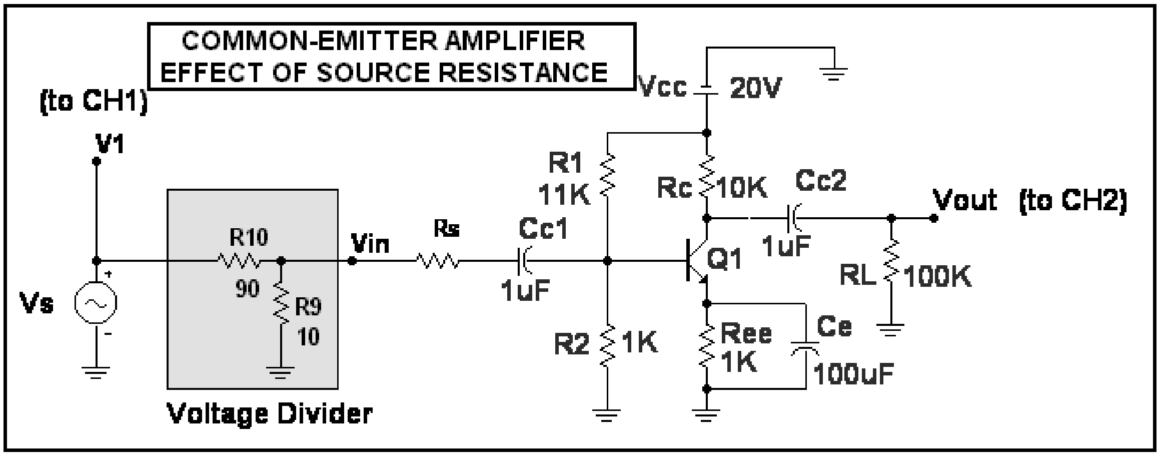
Run the Analysis.



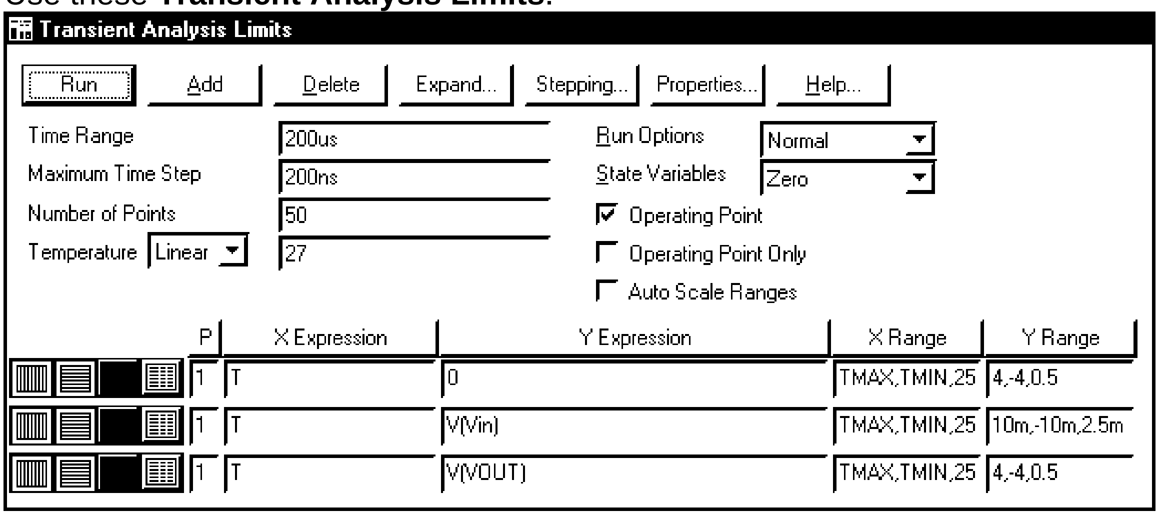
Find the frequencies at which the gain is down from its maximum or mid-frequency value by a factor of 1 over the square root of 2 = 0.7071. Find the corresponding frequencies in the actual circuit and compare the results with the simulation.

Exp 1.4 Effect of Signal Source Resistance on Voltage Gain

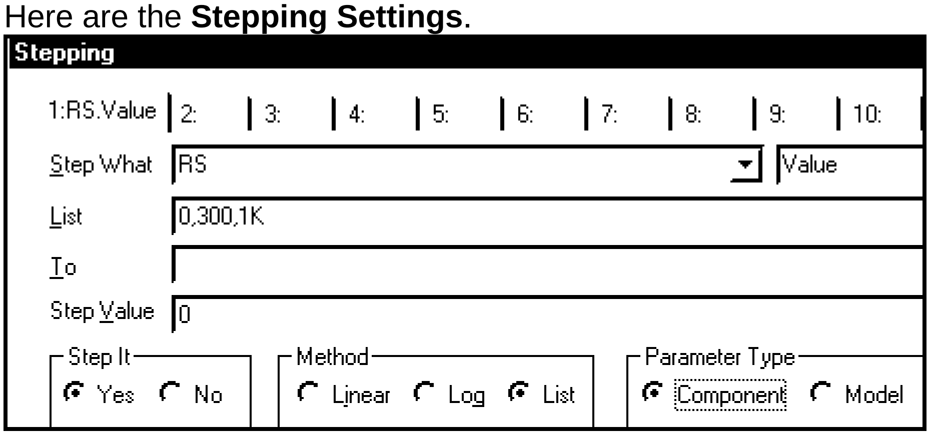
Add resistor R_S to the circuit in the simulation program and on the proto-board. Resistor R_S (plus the same contribution of the parallel combination of R_9 and R_{10}) represents the signal source resistance.



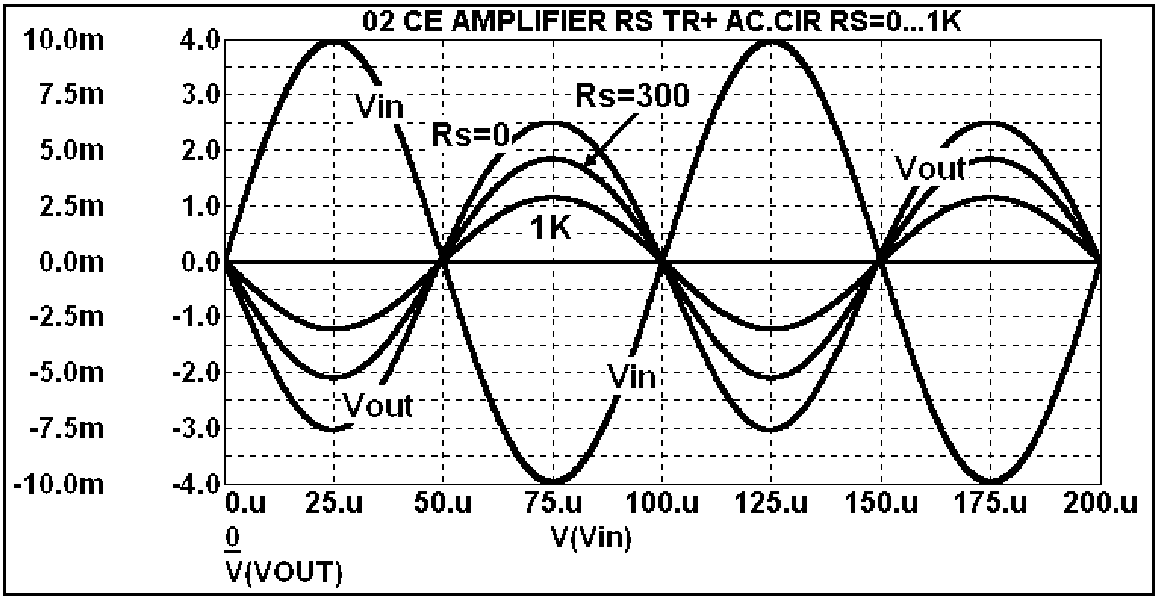
Use these **Transient Analysis Limits**.



Here are the **Stepping Settings**.



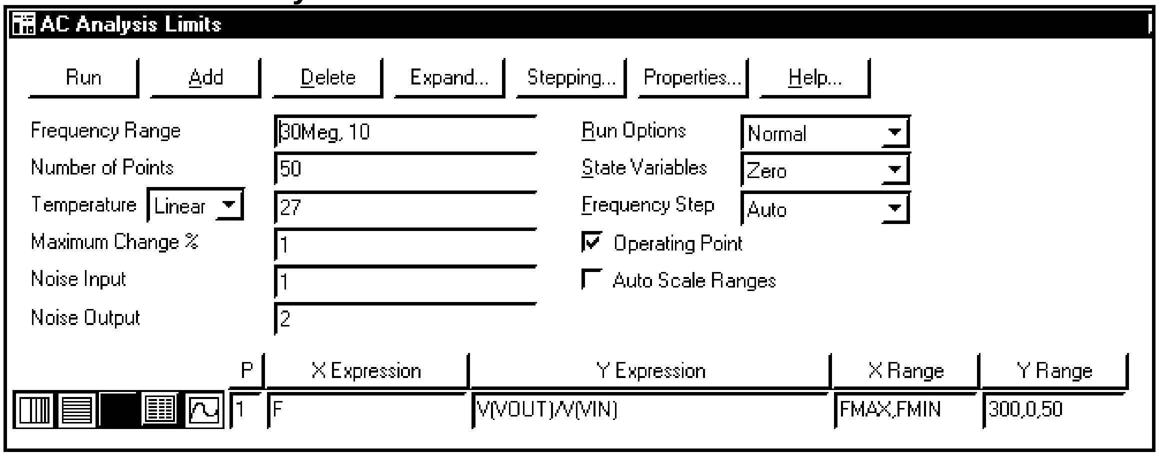
Run the Analysis.



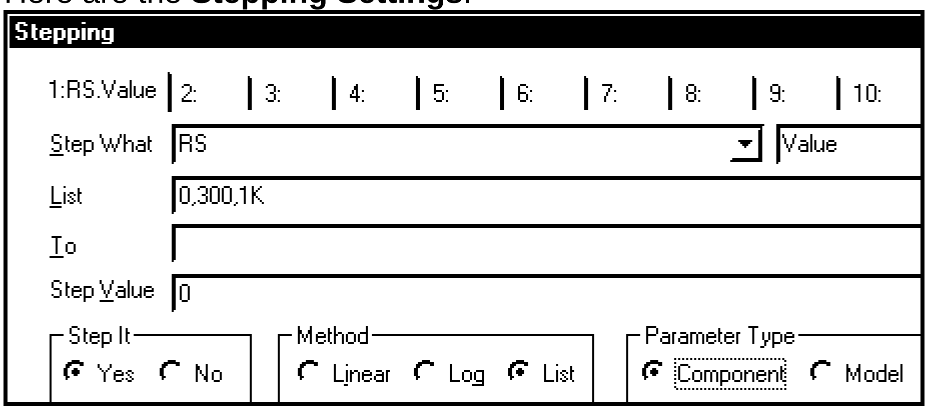
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. From these results, determine the input resistance that is seen looking from V_{IN} into the amplifier.

Exp 1.5 Effect of Signal Source Resistance on Voltage Gain

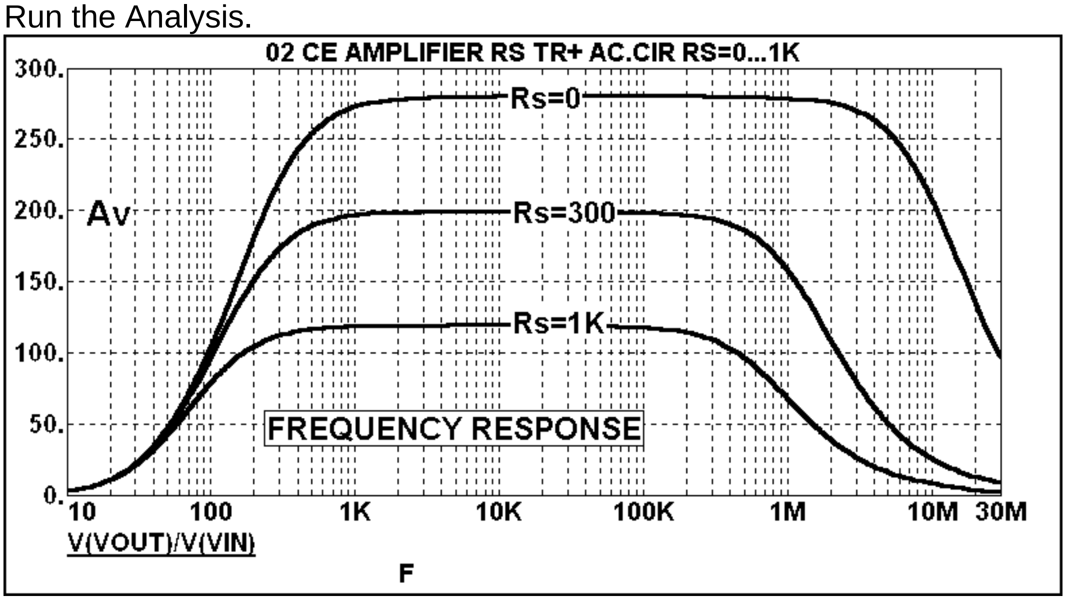
Use these **A-C Analysis Limits**.



Here are the **Stepping Settings**.



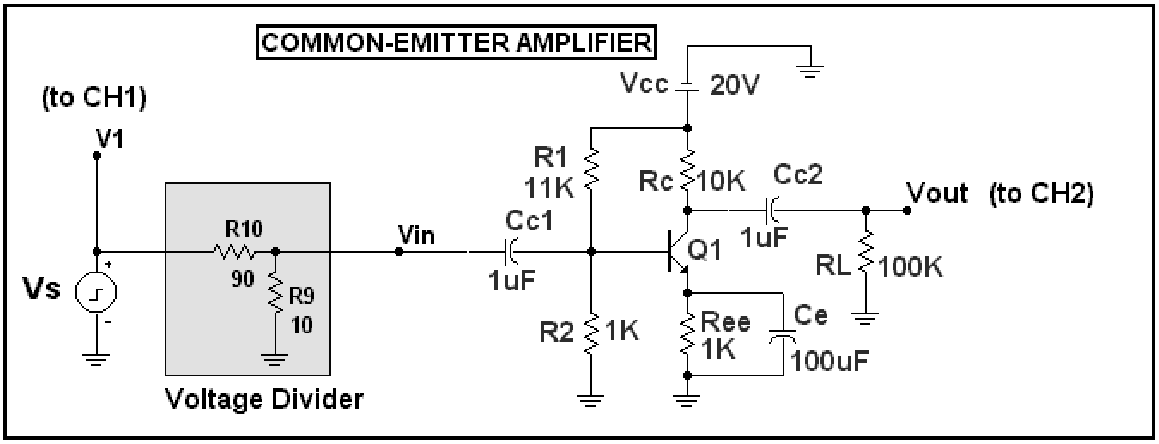
Run the Analysis.



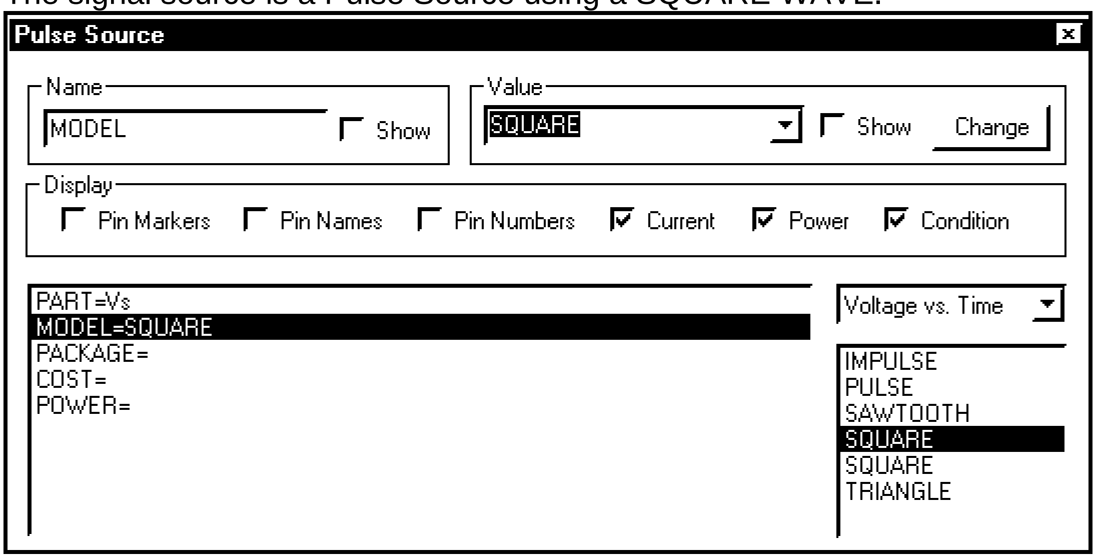
Find the frequencies at which the gain is down from its maximum or mid-frequency value by a factor of 1 over the square root of 2 = 0.7071. Find the corresponding frequencies in the actual circuit and compare the results with the simulation.

Exp 1.6 Time-Domain Response to a Pulse Input

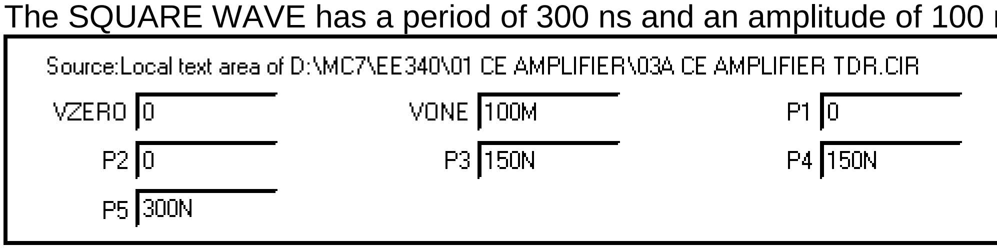
Change the signal source from a sine wave to a square wave in the simulation program and on the proto-board.



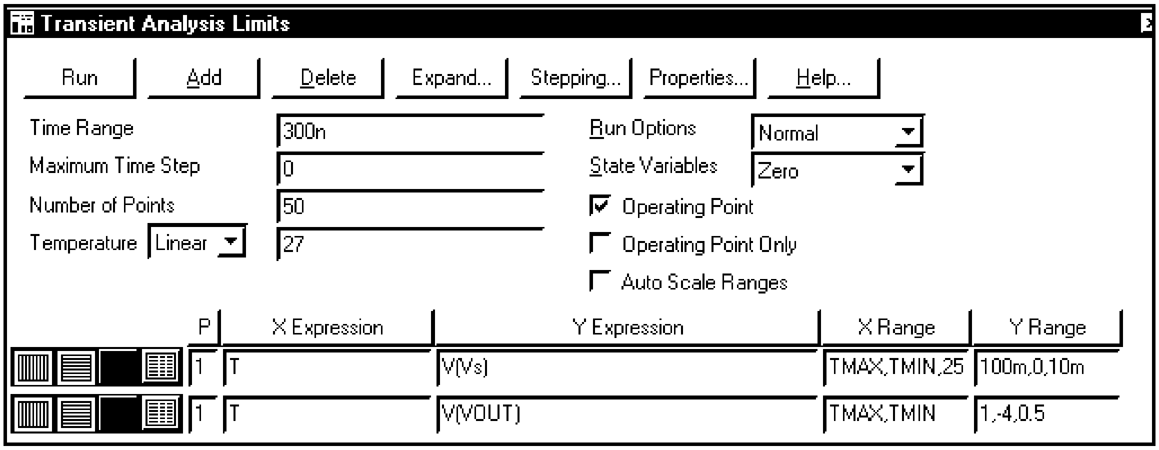
The signal source is a Pulse Source using a SQUARE WAVE.



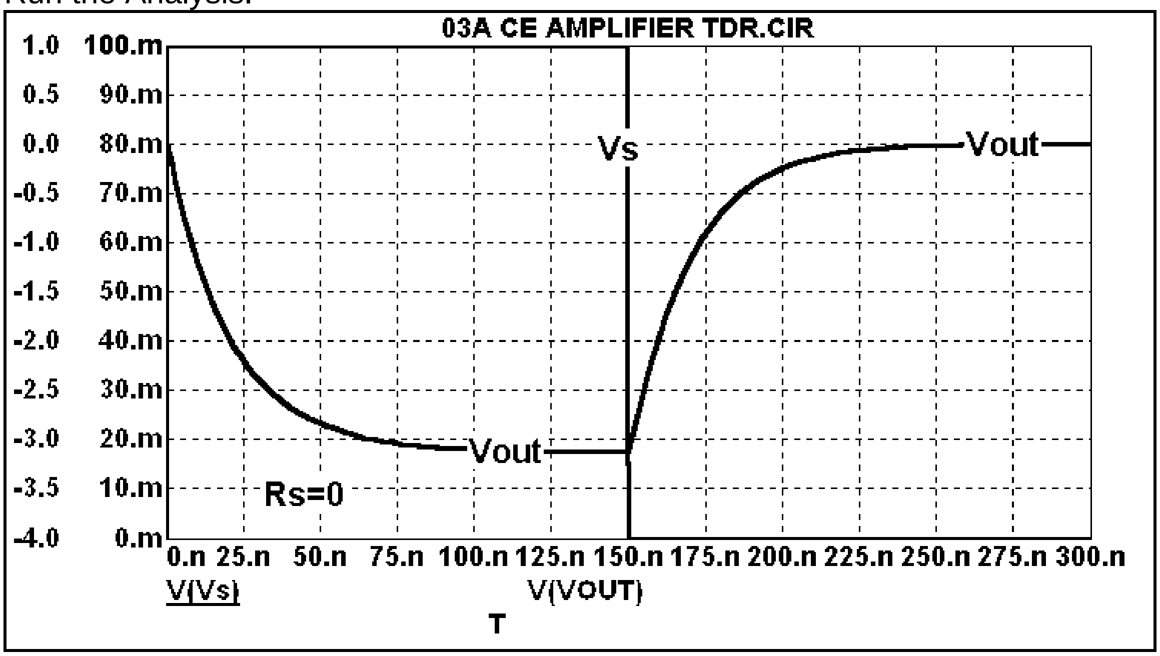
The SQUARE WAVE has a period of 300 ns and an amplitude of 100 mV.



Use these **Transient Analysis Limits**.



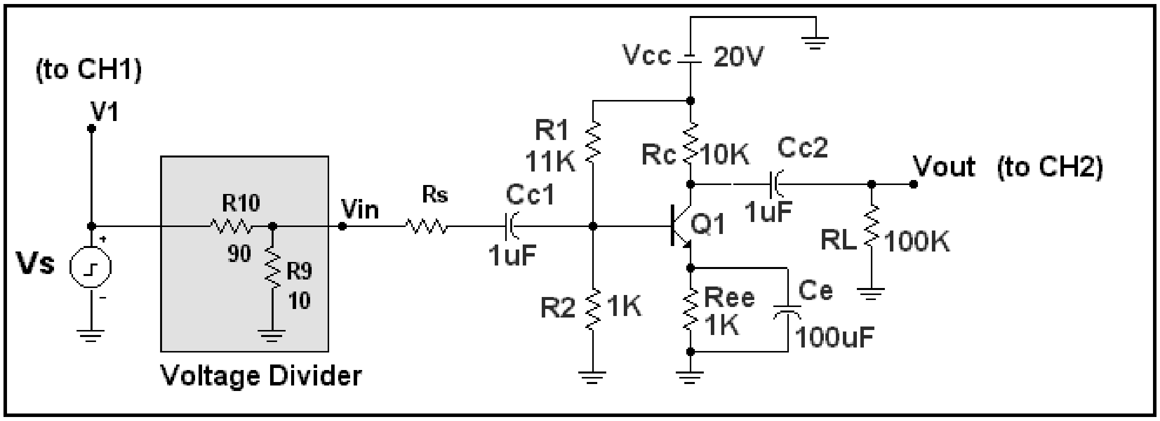
Run the Analysis.



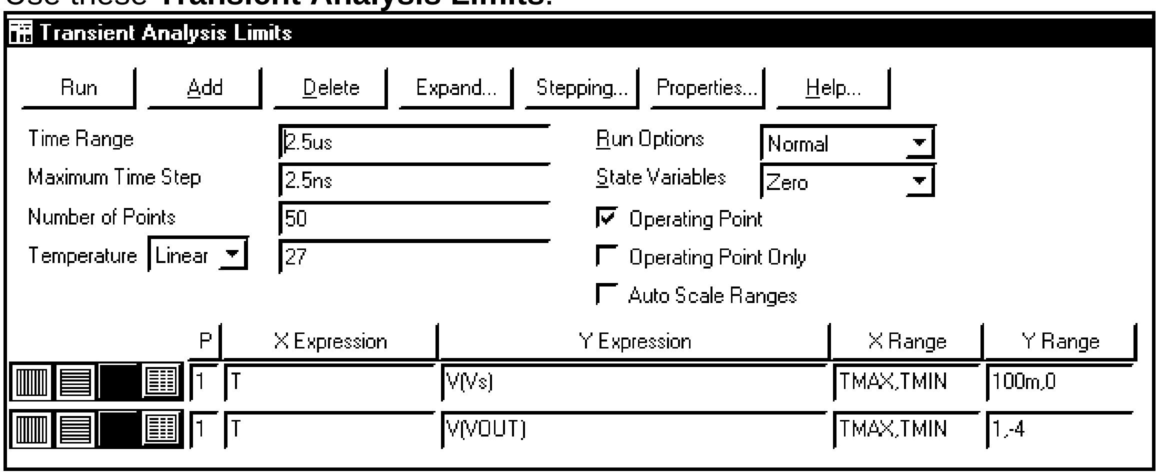
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. Find the 10% to 90% rise time and the 90% to 10% fall time of the actual circuit and compare with the simulation.

Exp 1.7 Effect of Rs on the Time-Domain Response to a Pulse Input

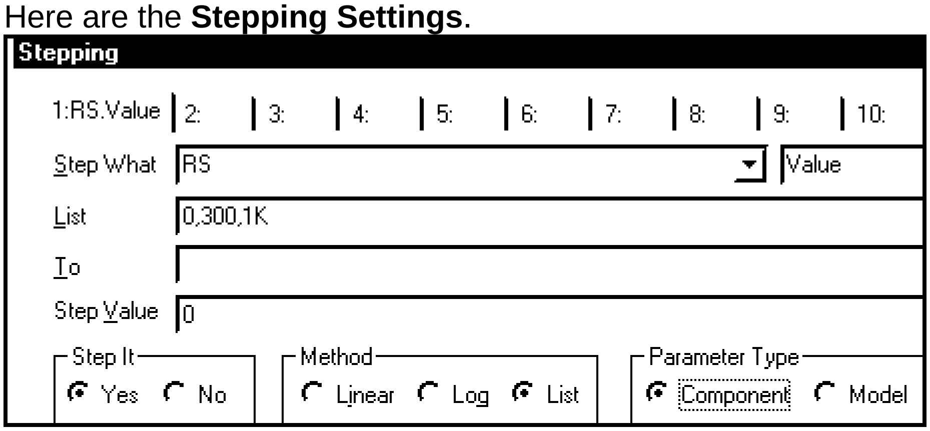
Add resistor R_S to the circuit in the simulation program and on the proto-board. Resistor R_S (plus the same contribution of the parallel combination of R_9 and R_{10}) represents the signal source resistance.



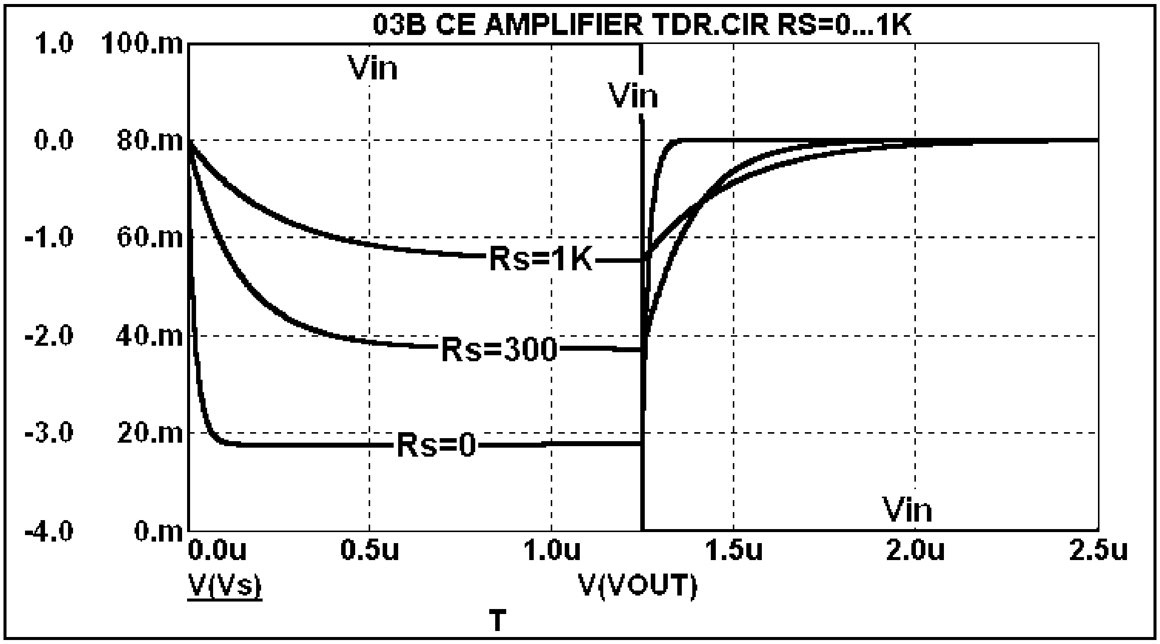
Use these **Transient Analysis Limits**.



Here are the **Stepping Settings**.



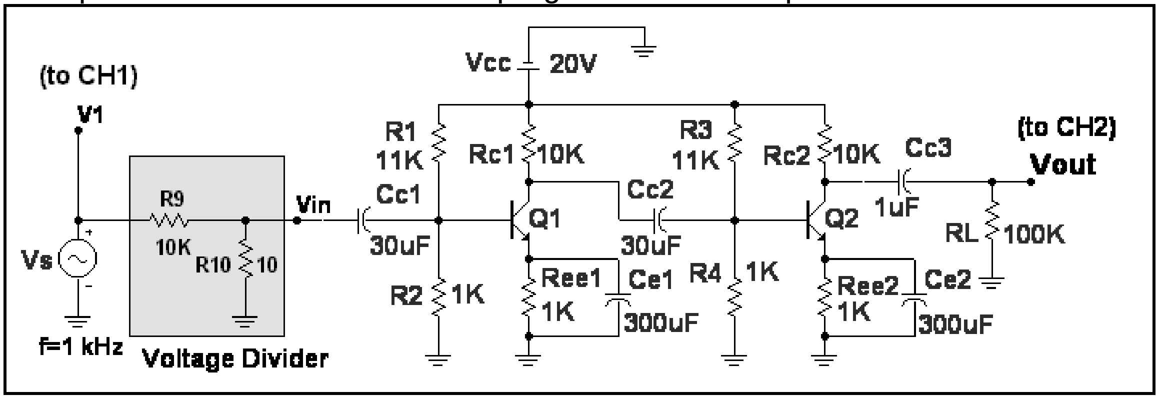
Run the Analysis.



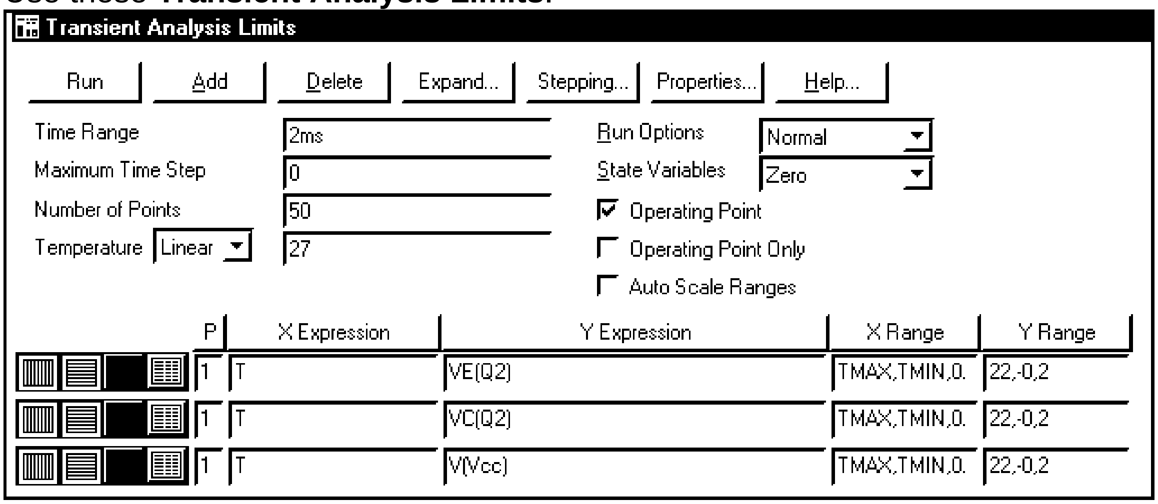
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

Exp 2.1 Effect of Input Signal Level on Two-Stage Cascaded Amplifier

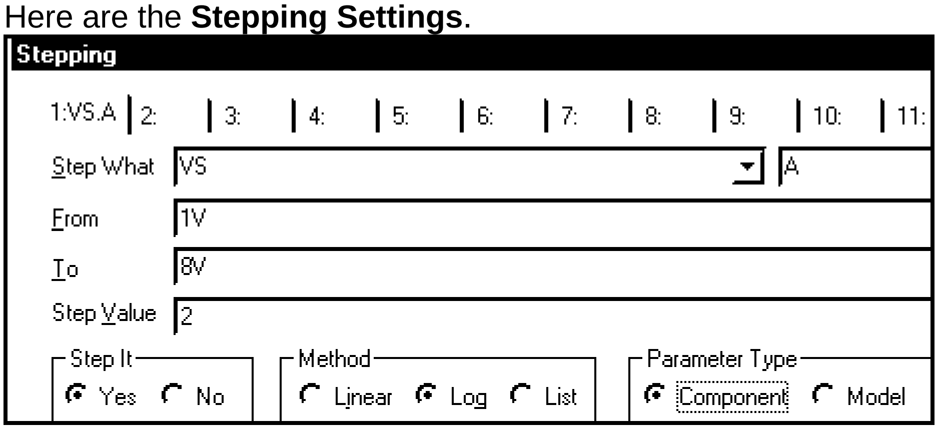
Set up this circuit in the simulation program and on the proto-board.



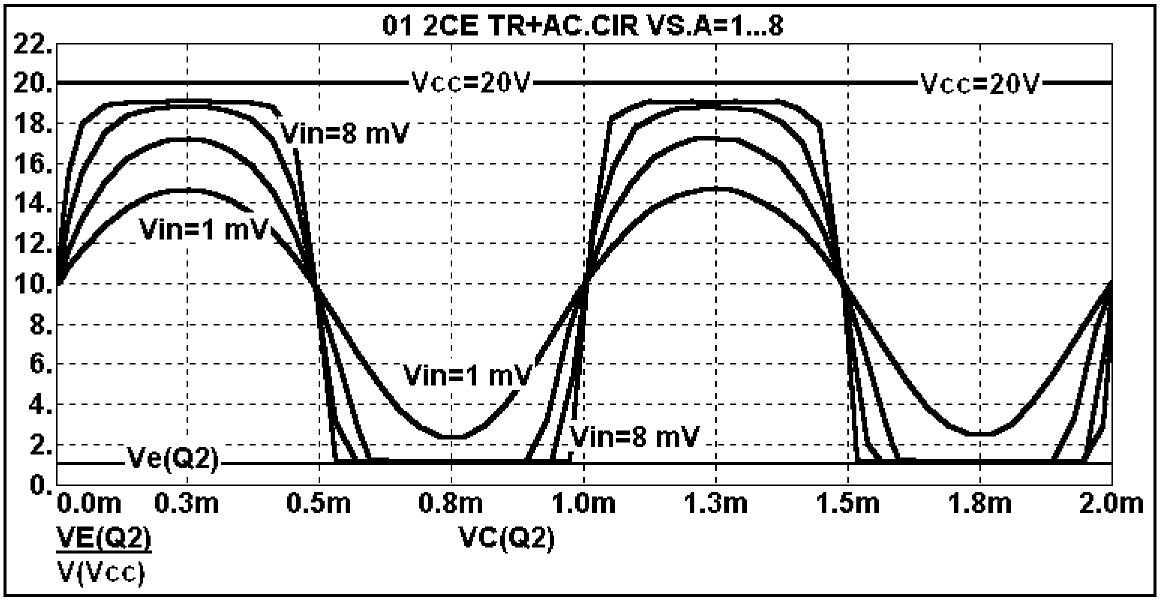
Use these **Transient Analysis Limits**.



Here are the **Stepping Settings**.



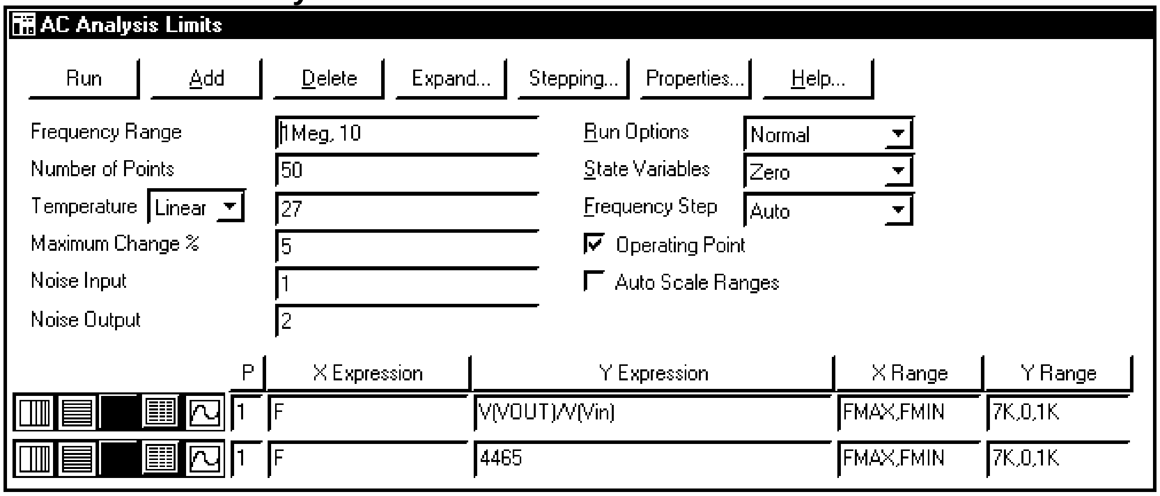
Run the Analysis.



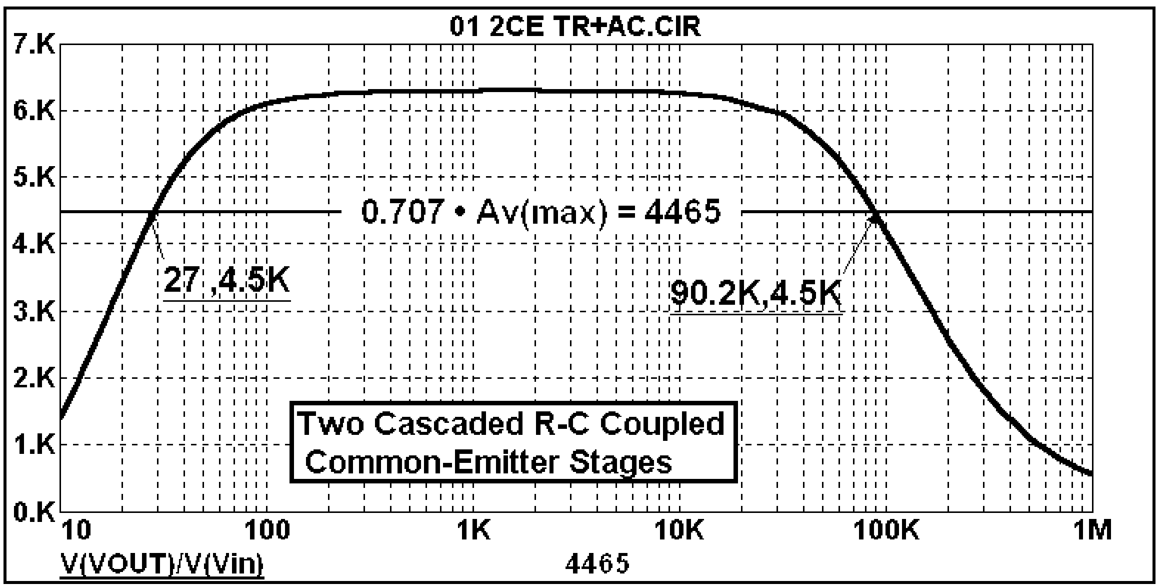
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

Exp 2.2 Frequency Response Two-Stage Cascaded Amplifier

Use these **A-C Analysis Limits**.



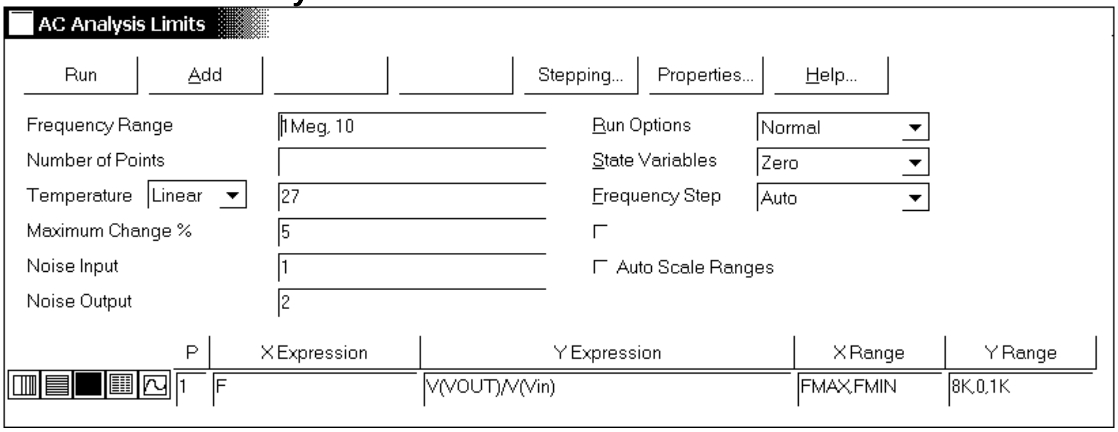
Run the Analysis.



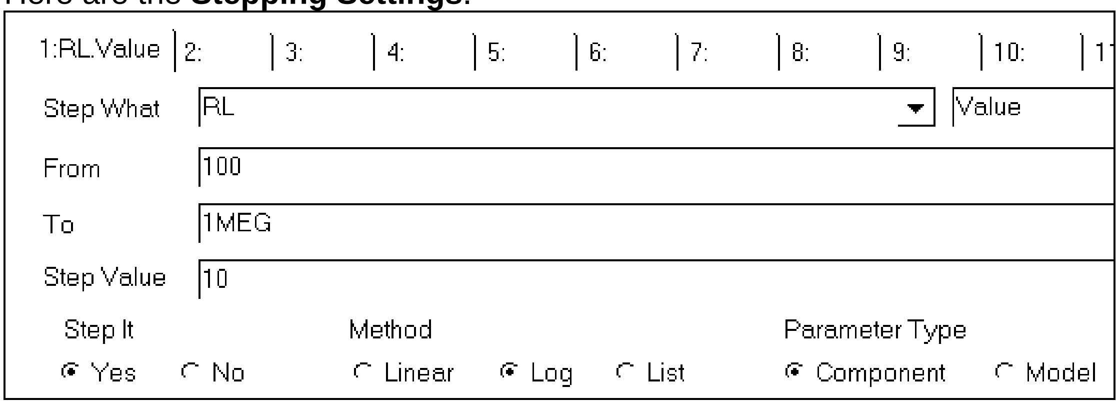
Find the frequencies at which the gain is down from its maximum or mid-frequency value by a factor of 1 over the square root of 2 = 0.7071. Find the corresponding frequencies in the actual circuit and compare the results with the simulation.

Exp 2.3 Effect of Load Resistance on Voltage Gain

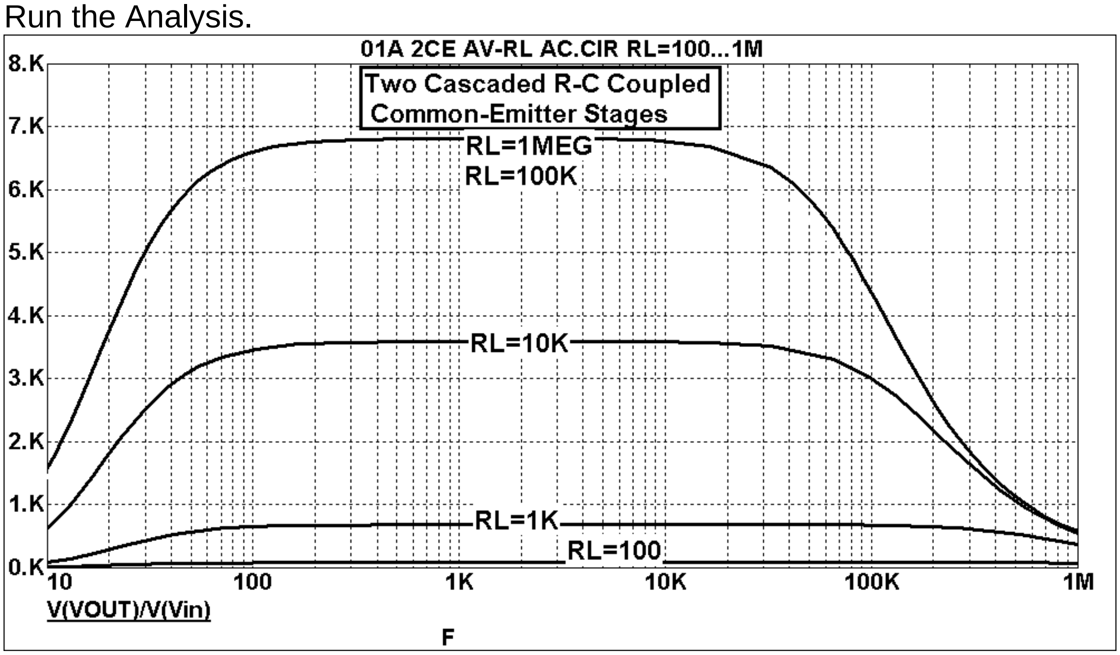
Use these **A-C Analysis Limits**.



Here are the **Stepping Settings**.



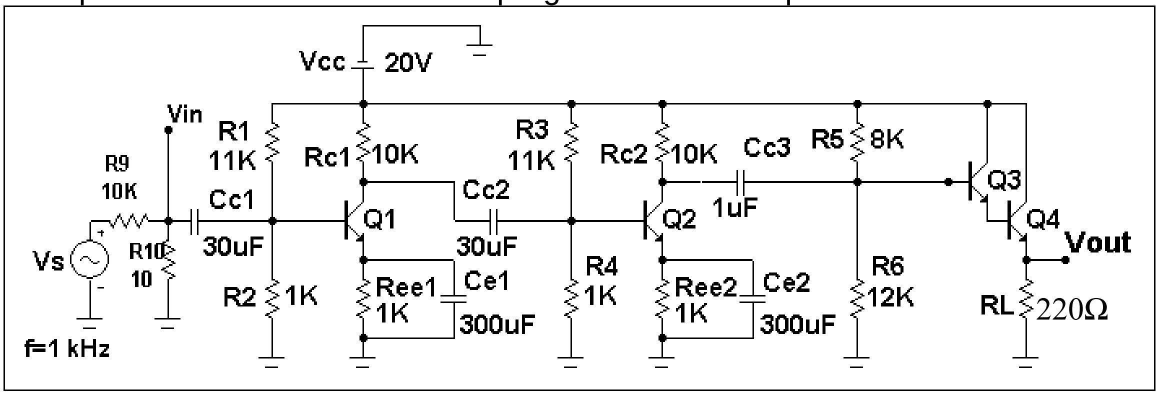
Run the Analysis.



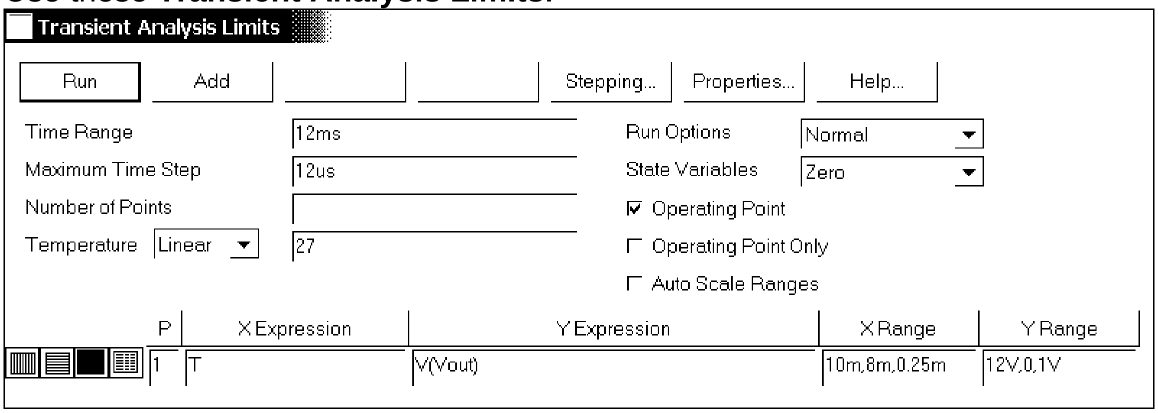
Measure the voltage gain of the actual circuit at f=1 kHz. Compare the results with the values obtained from the simulation.

Exp 2.4 Voltage Gain and Effect of the Input Signal Level

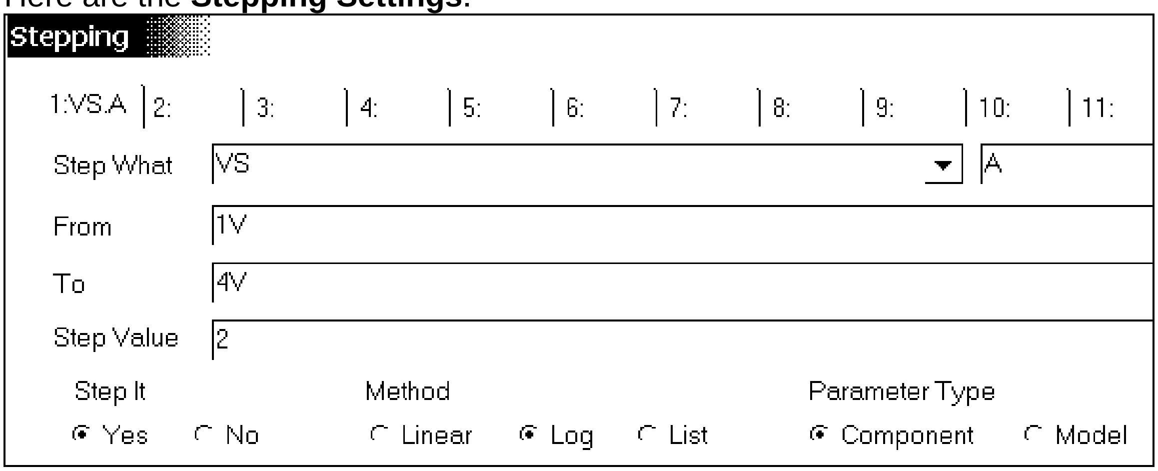
Set up this circuit in the simulation program and on the proto-board.



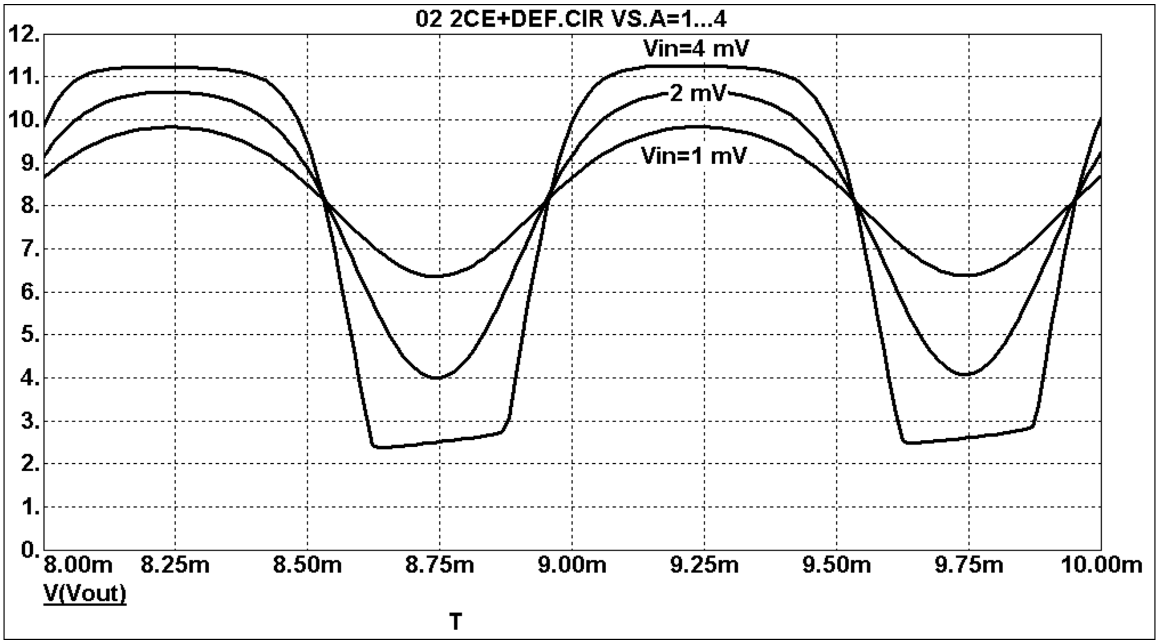
Use these **Transient Analysis Limits**.



Here are the **Stepping Settings**.



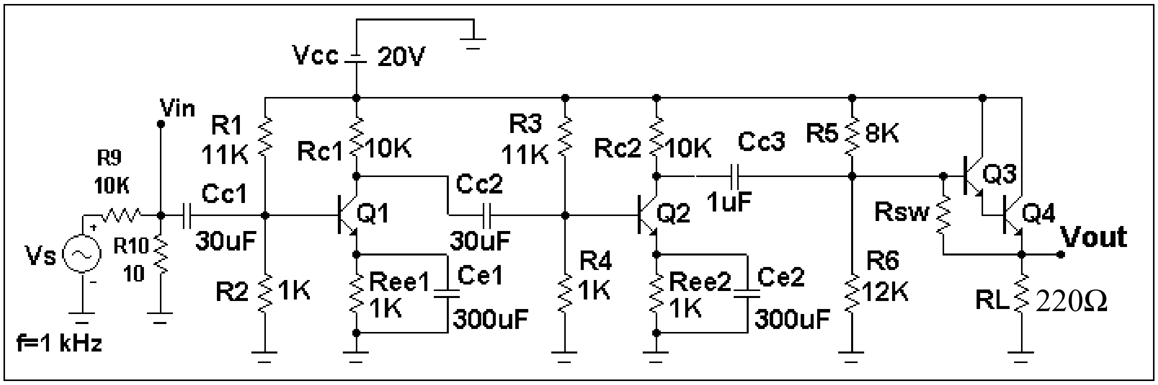
Run the Analysis.



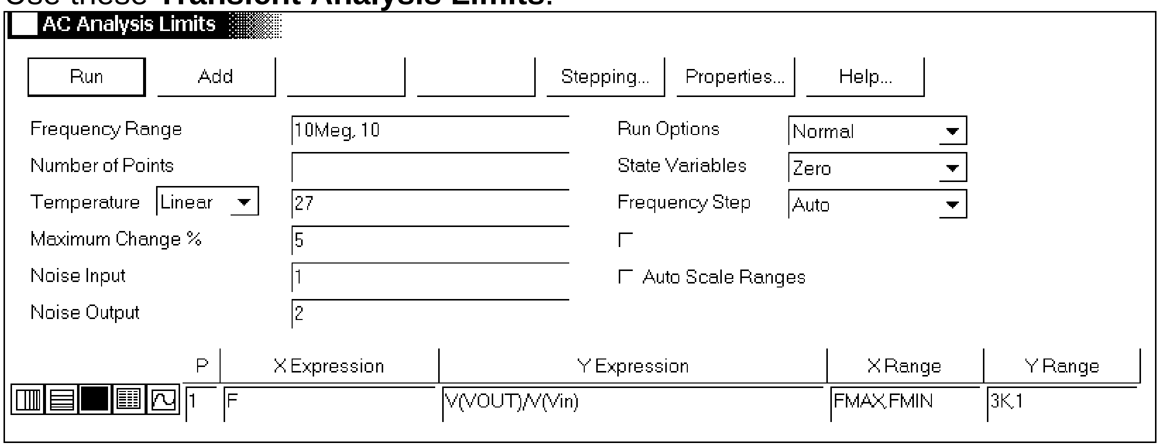
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. Note that Vin is equal to Vs times the voltage division ratio produced by the R_9-R_{10} voltage divider. In this example the voltage division ratio is $R_{10}/(R_9+R_{10})$= 10/(10K+10) = 0.001.

Exp 2.5 Comparison of Voltage Gain with and without the Darlington Emitter-Follower for Impedance Transformation.

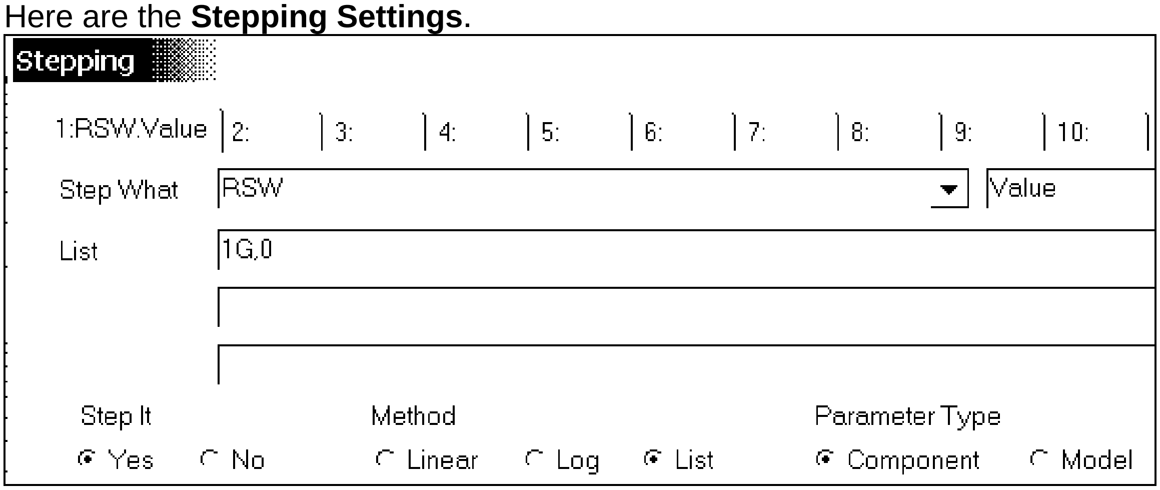
Modify the circuit in the simulation program by adding resistor R_{SW}. This resistor can have any value such as 1 KΩ.



Use these **Transient Analysis Limits**.

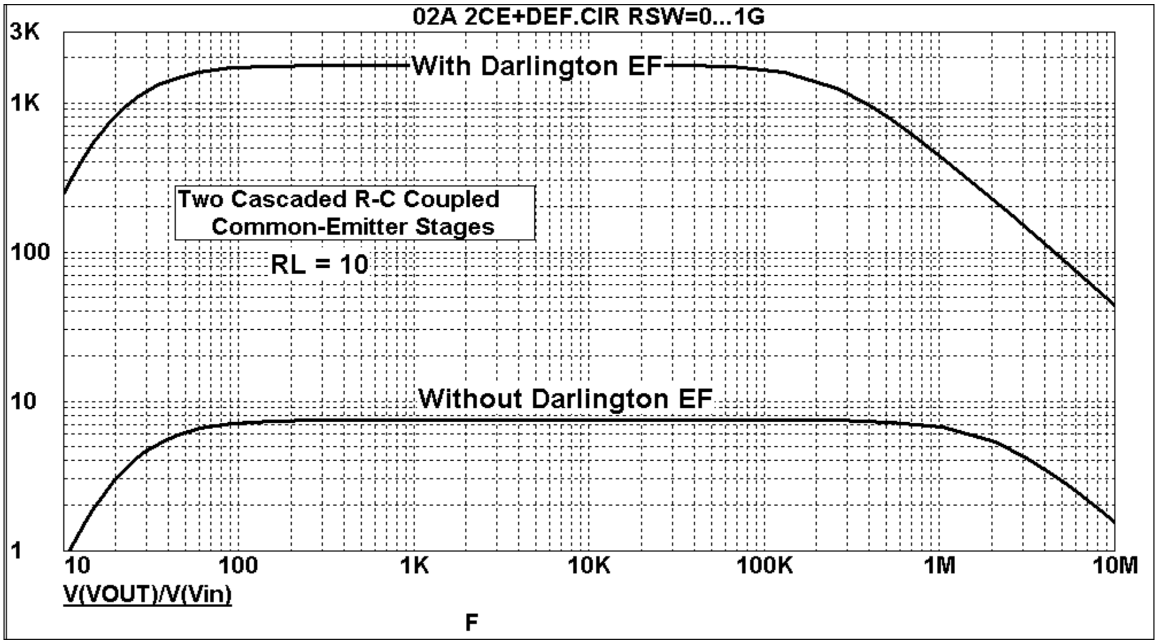


Here are the **Stepping Settings**.



Note that resistor RSW will be stepped from 1 GΩ to 0. When R_{SW} = 0, the Q_3-Q_4 Darlington pair is bypassed by R_{SW}, and thus has no effect. R_{SW} = 1 GΩ, it acts essentially like an open-circuit and the Q_3-Q_4 Darlington pair is no longer bypassed by R_{SW}.

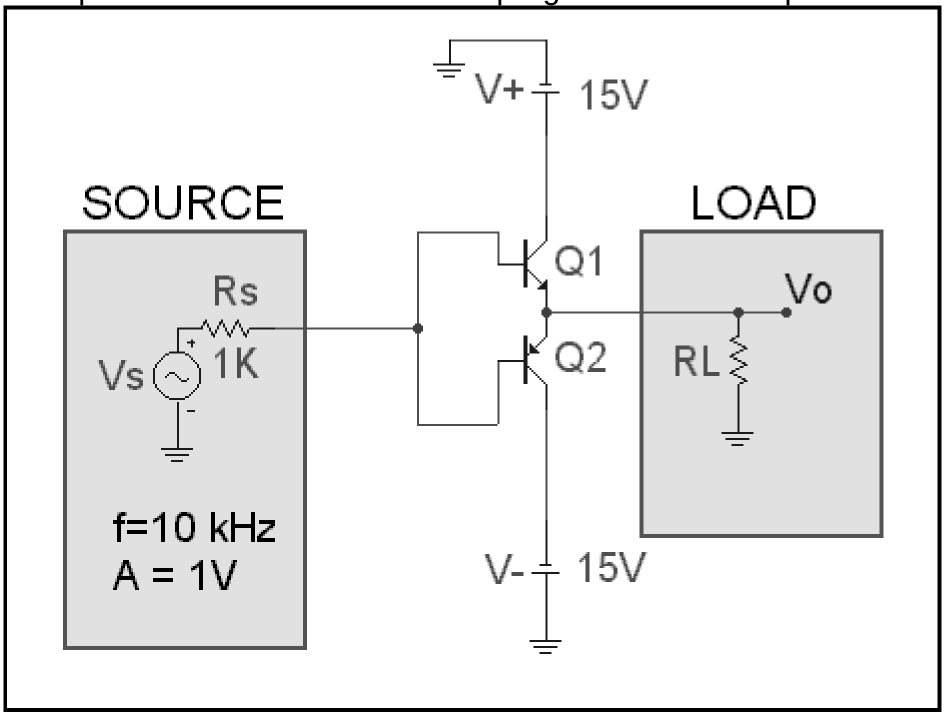
Run the Analysis.



Measure voltage gain of the circuit at f = 1 kHz with the Darlington pair bypassed by a short-circuit, and for the case of it not being bypassed. Compare the results with the simulation.

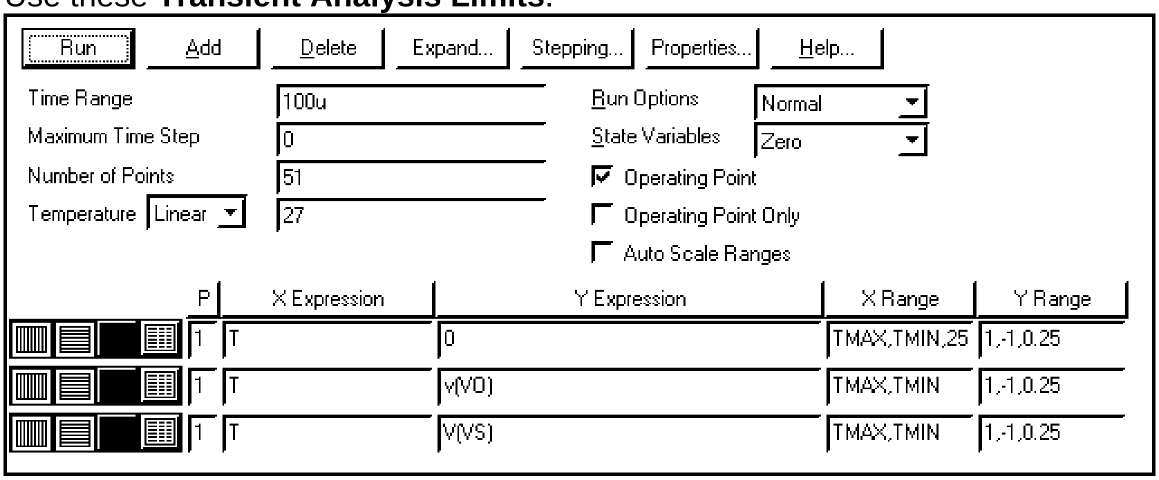
Exp 3.1 Push-Pull Circuit

Set up this circuit in the simulation program and on the proto-board.

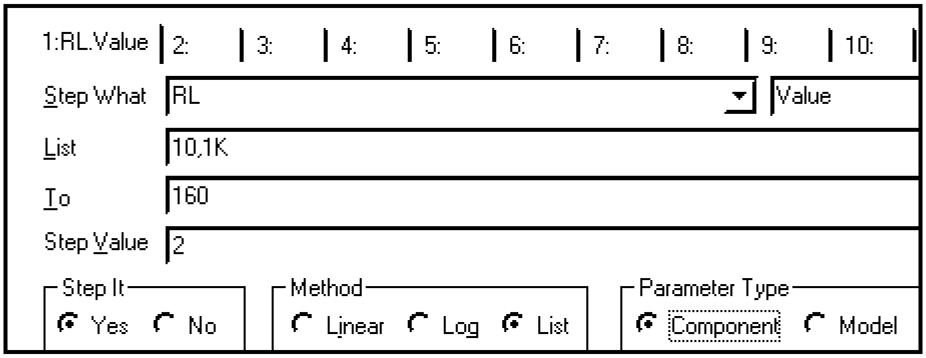


Transistor Q1 can be any suitable NPN transistor such as a 2N4124 or a 2N2222. Transistor Q1 can be any suitable PNP transistor such as a 2N3906.

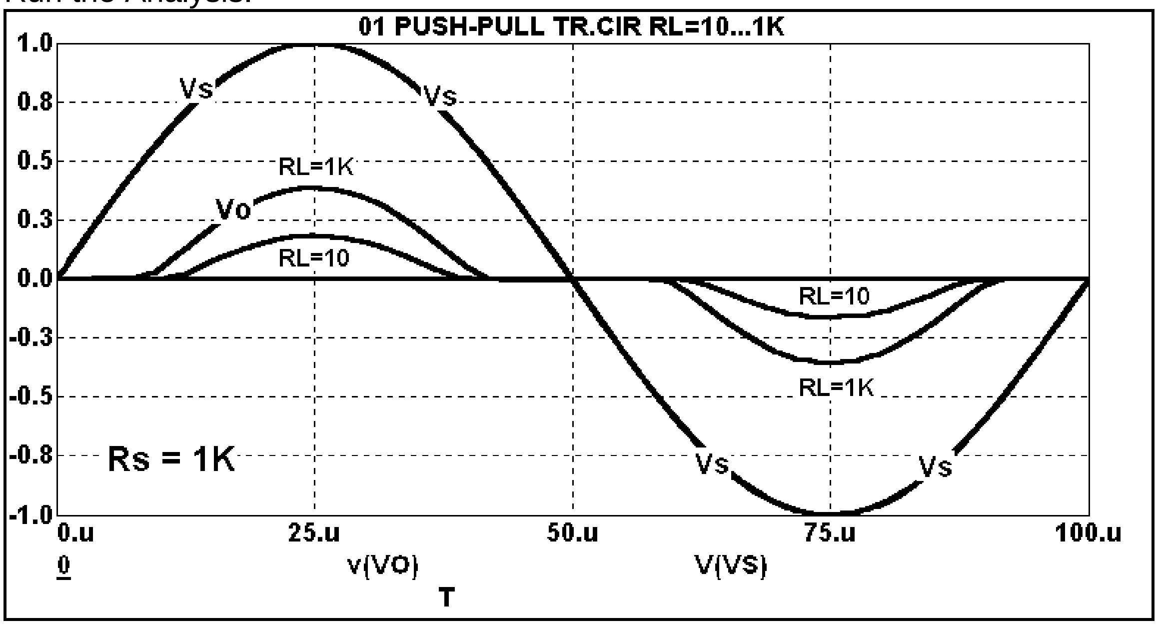
Use these **Transient Analysis Limits**.



Here are the **Stepping Settings**.



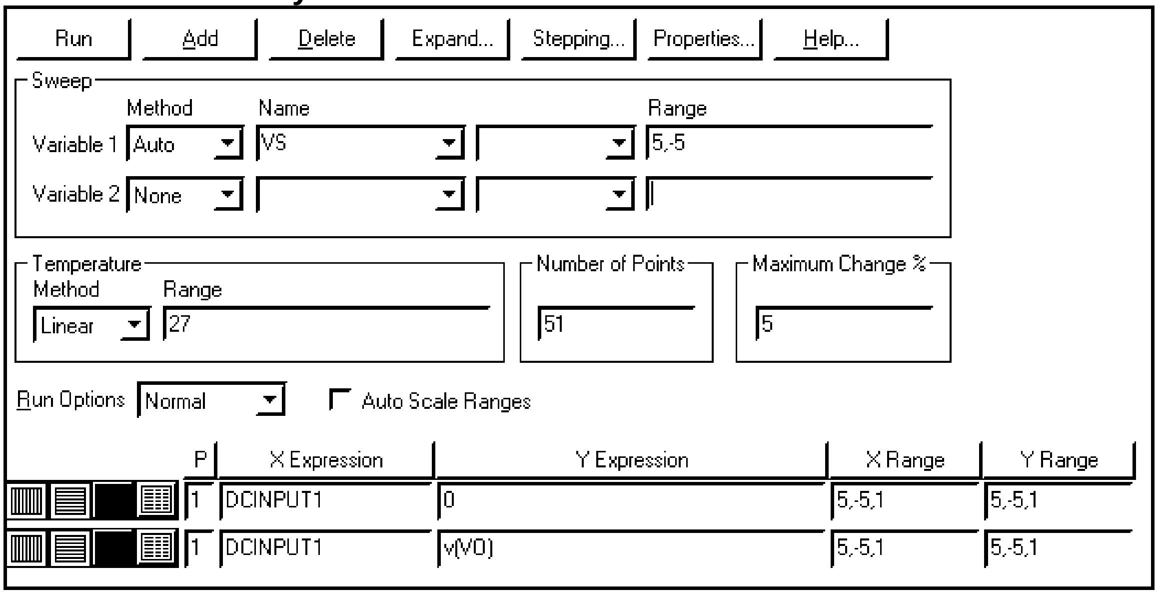
Run the Analysis.



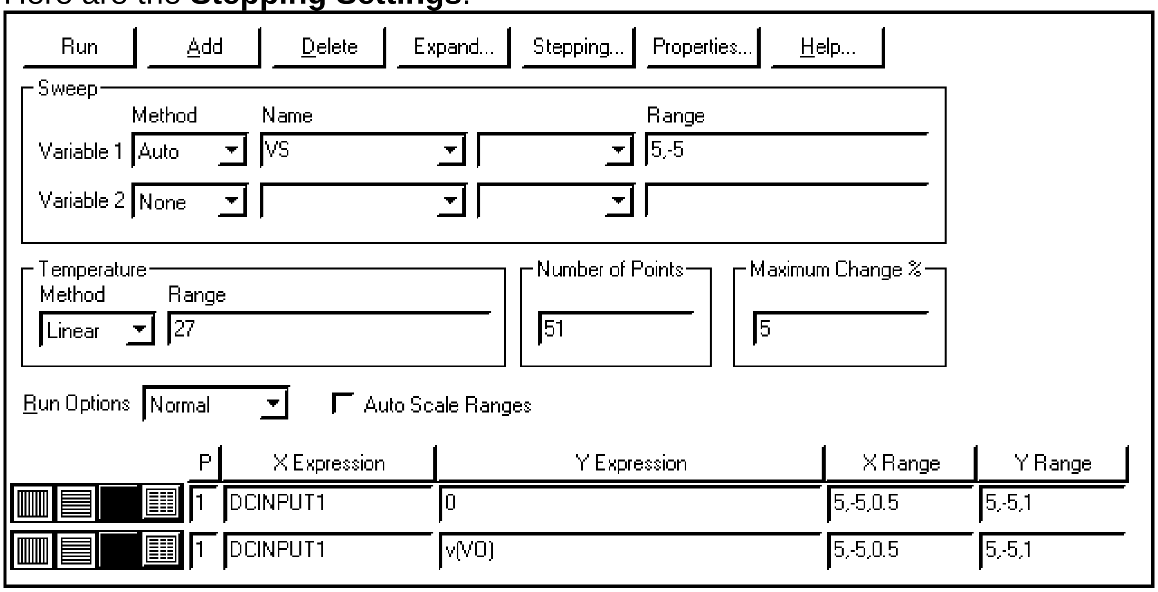
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. Note the “crossover distortion” in the region where both transistors are off.

Exp 3.2 Voltage Transfer Curve

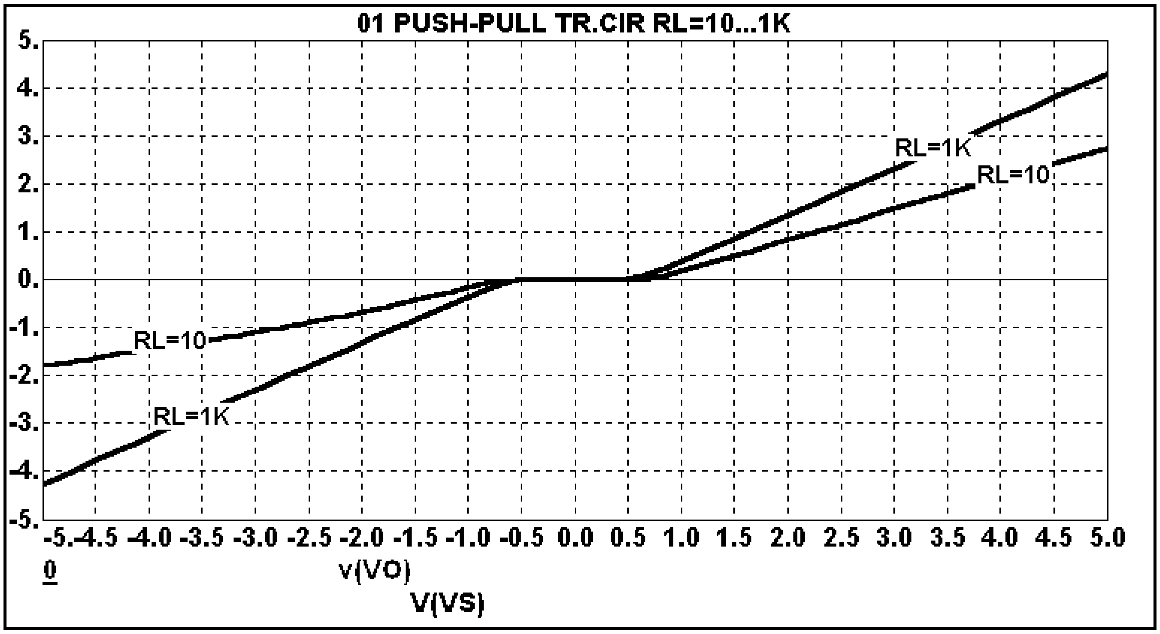
Use these **D-C Analysis Limits**.



Here are the **Stepping Settings**.



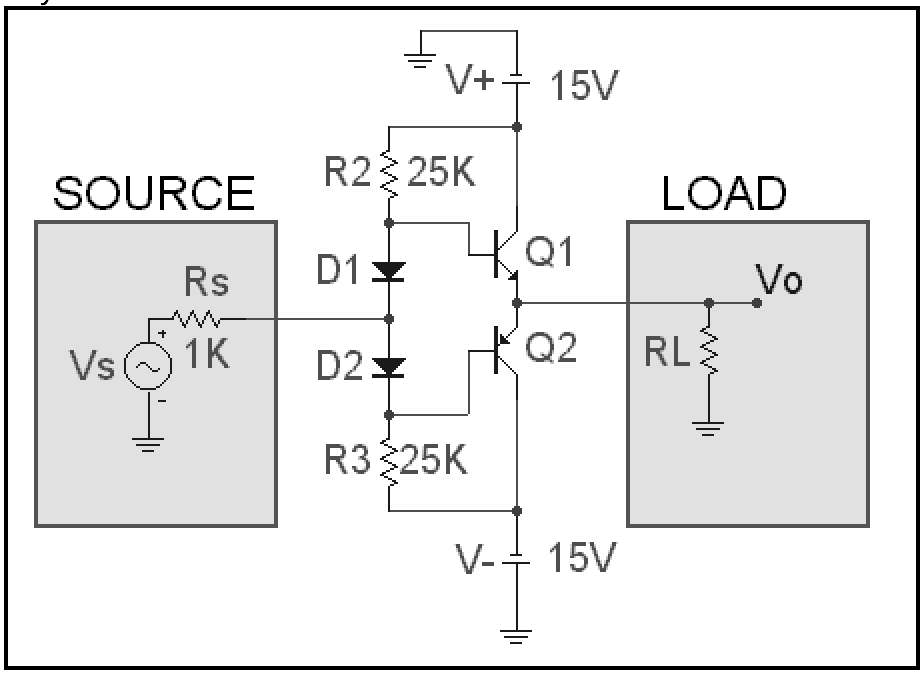
Run the Analysis.



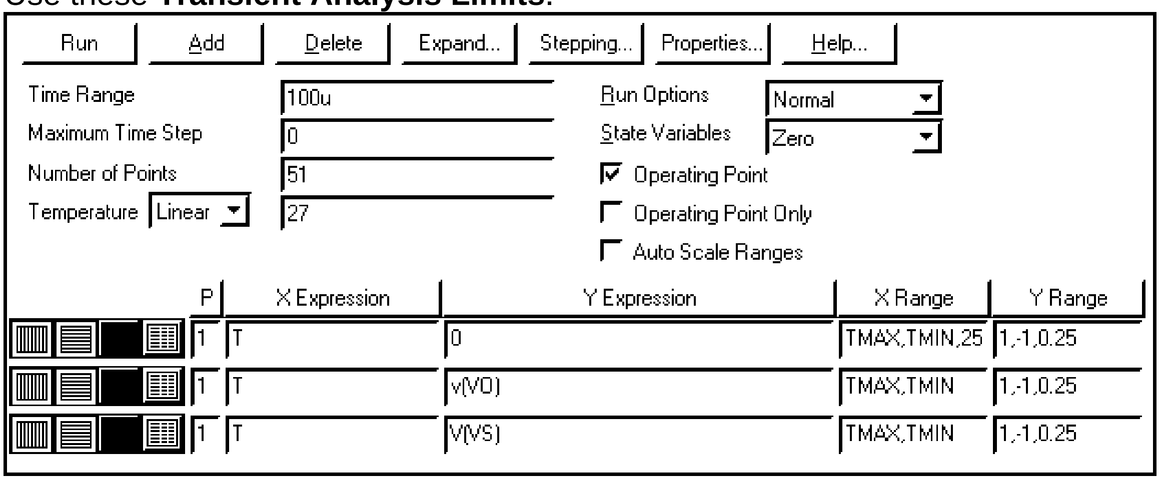
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. What is the width of the "crossover distortion" region where both transistors are off?

Exp 3.3 Minimizing Crossover Distortion

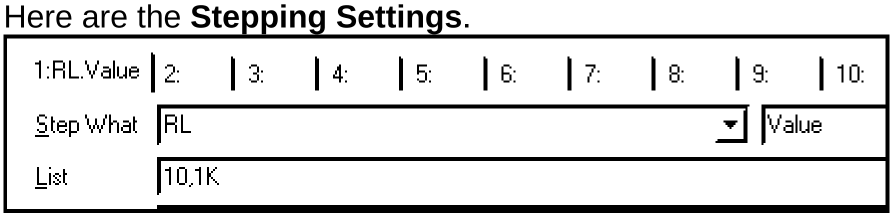
Set up this circuit in the simulation program and on the proto-board. Diodes D_1 and D_2 can be any suitable diode such as a 1N4001 or a 1N914.



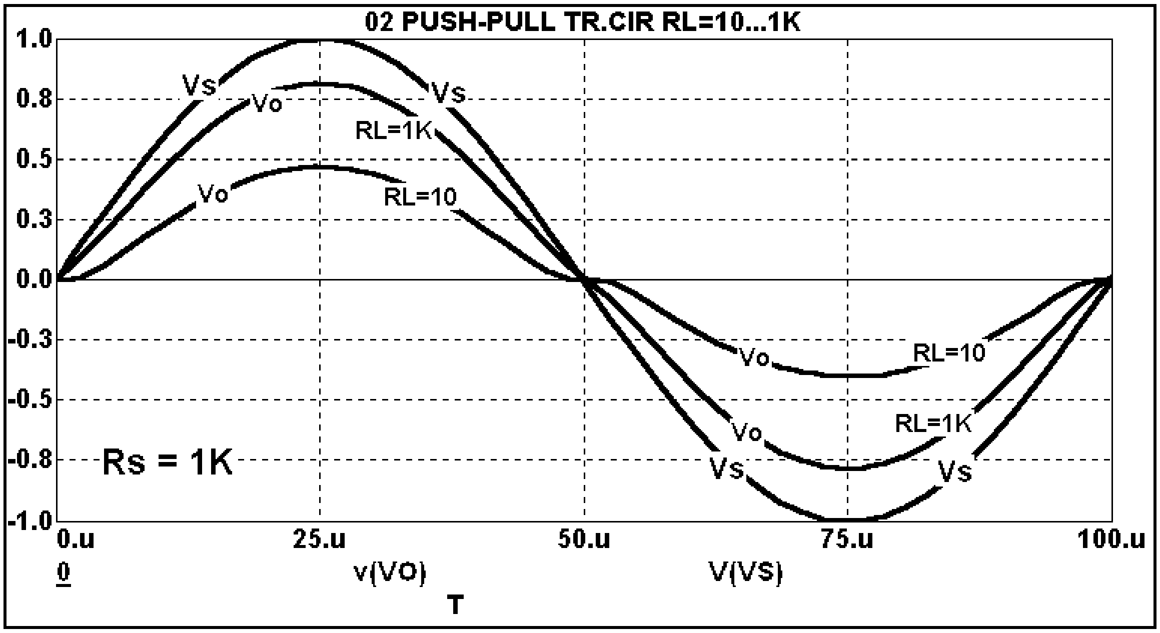
Use these **Transient Analysis Limits**.



Here are the **Stepping Settings**.



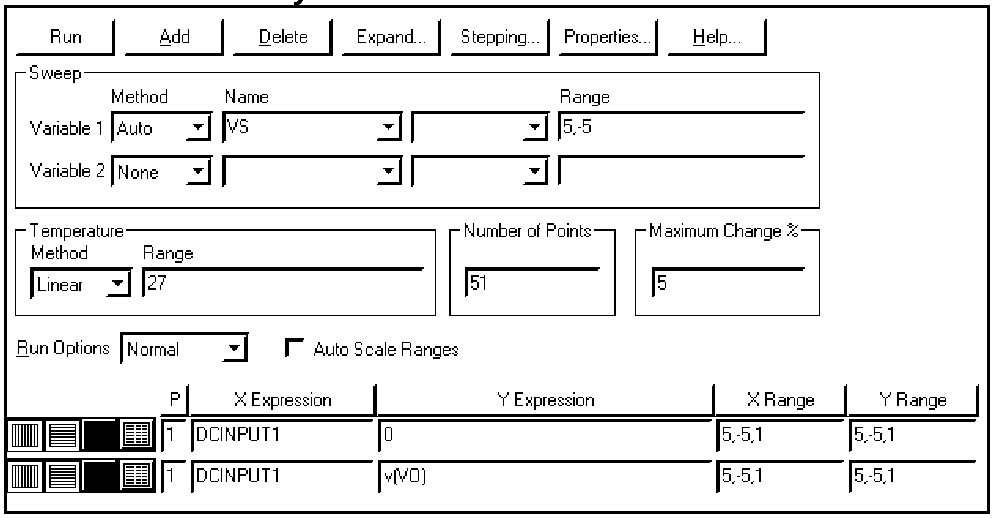
Run the Analysis.



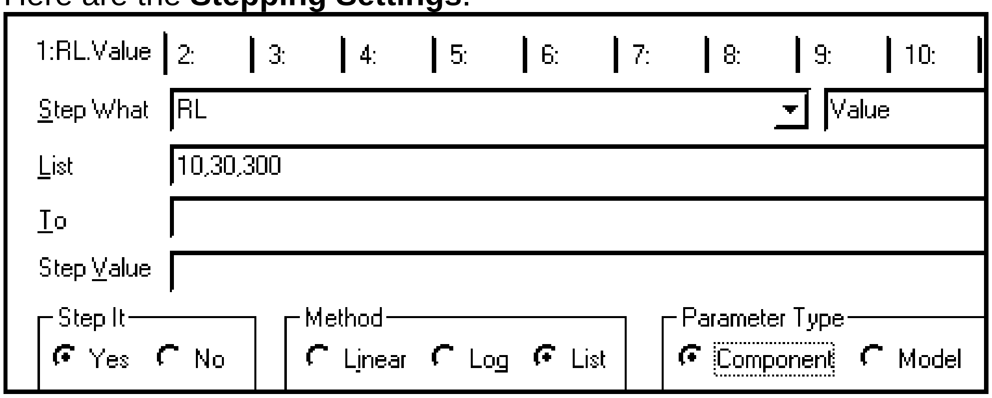
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. Compare the crossover distortion to the previous case.

Exp 3.4 Minimizing Crossover Distortion Voltage Transfer Curve

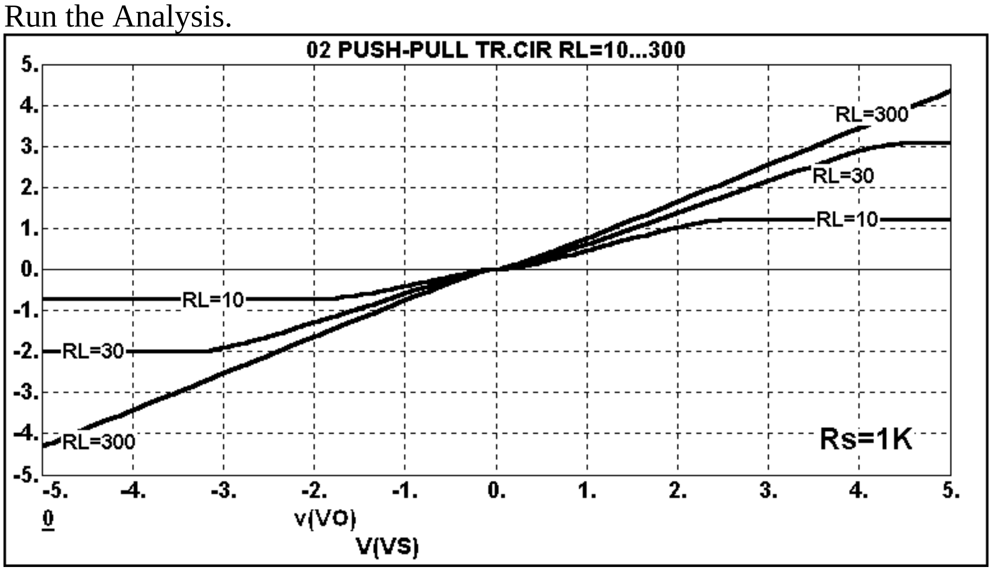
Use these **D-C Analysis Limits**.



Here are the **Stepping Settings**.



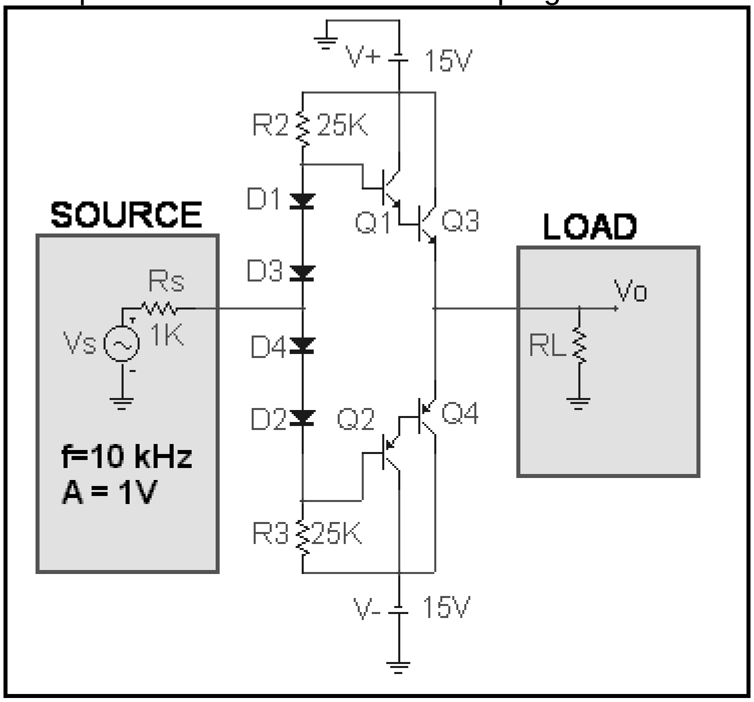
Run the Analysis.



Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. What is the width of the “crossover distortion” region where both transistors are off?

Exp 3.5 Using Darlington Emitter-Followers

Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis Limits**.

Time Range	100u
Maximum Time Step	0
Number of Points	51
Temperature (Linear)	27
Run Options	Normal
State Variables	Zero
Operating Point	☑
Operating Point Only	☐
Auto Scale Ranges	☐

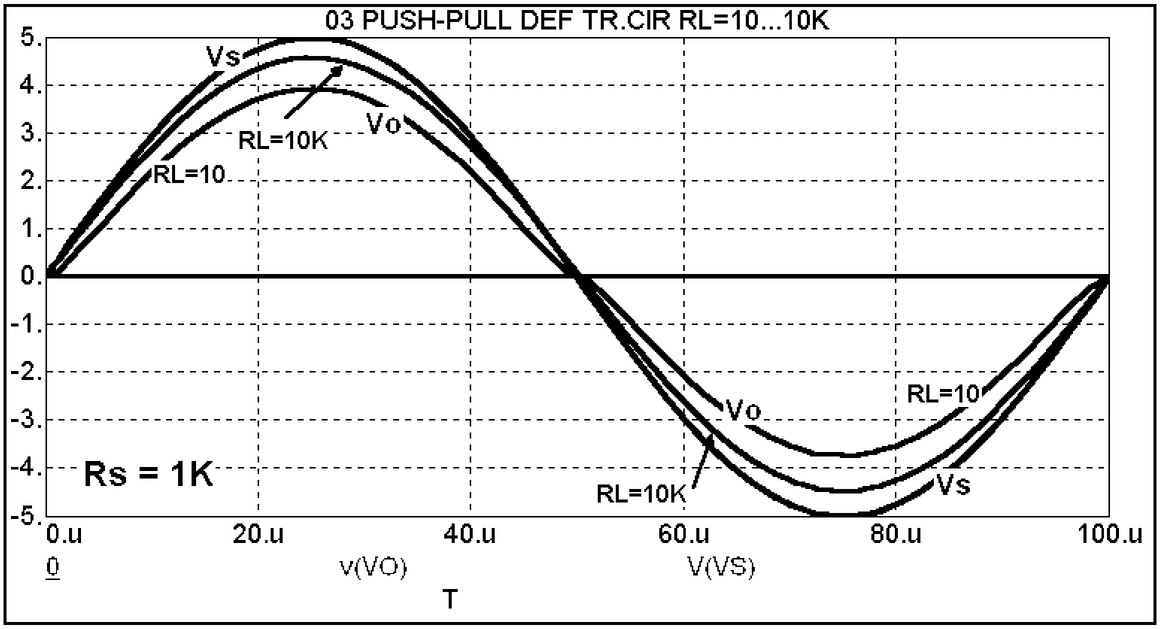
P	X Expression	Y Expression	X Range	Y Range
1	T	0	TMAX,TMIN	5,-5,1
1	T	v(VO)	TMAX,TMIN	5,-5,1
1	T	V(VS)	TMAX,TMIN	5,-5,1

Here are the **Stepping Settings**.

Step What	RL (Value)
List	10,10K
To	160
Step Value	2
Step It	● Yes ○ No
Method	○ Linear ○ Log ● List
Parameter Type	● Component ○ Model

Run the Analysis.

PUSH-PULL CIRCUITS Using Darlington Emitter-Followers   EXPERIMENT 3.5

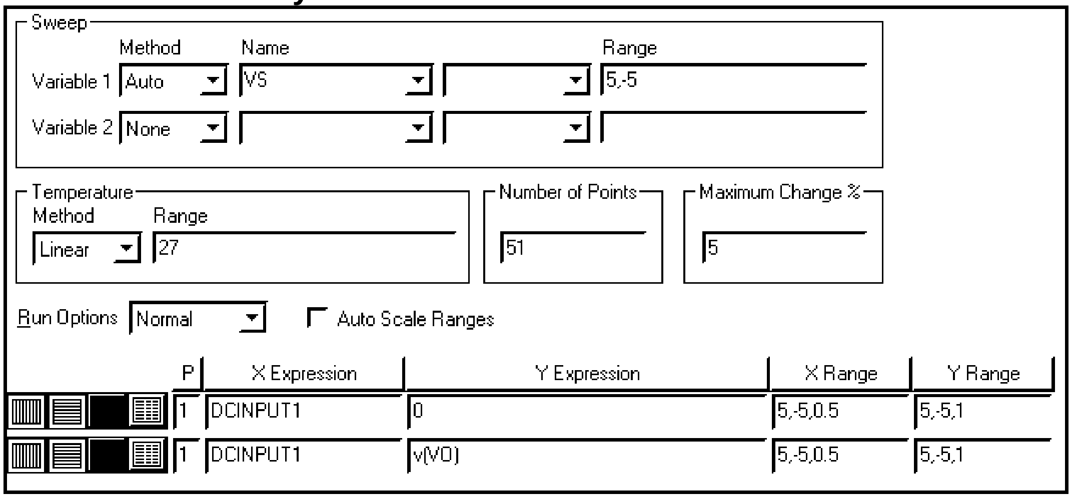


Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

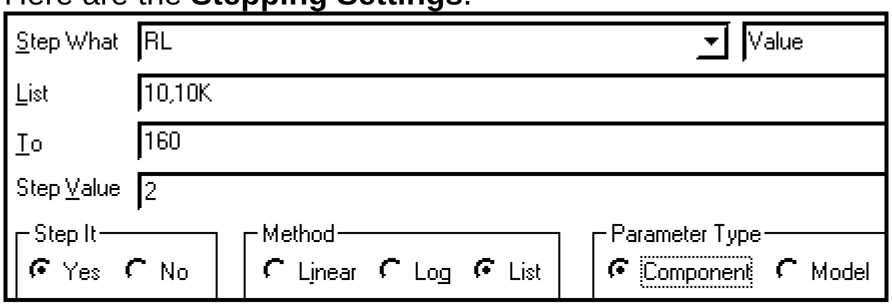
PUSH-PULL CIRCUITS Using Darlington Emitter-Followers   EXPERIMENT 3.6

Exp 3.6   Voltage Transfer Curves

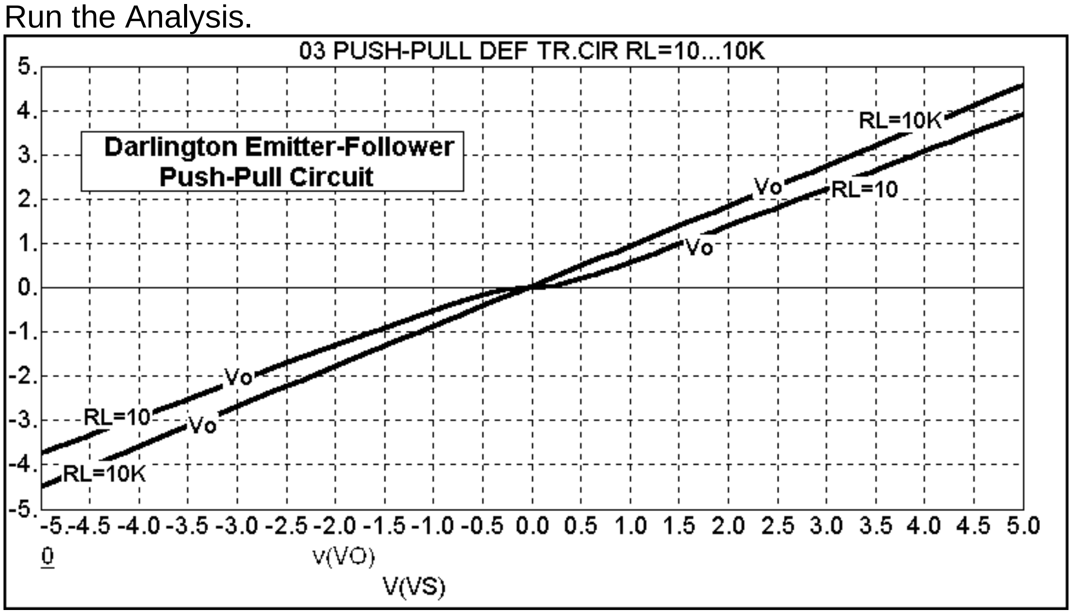
Use these **D-C Analysis Limits**.



Here are the **Stepping Settings**.



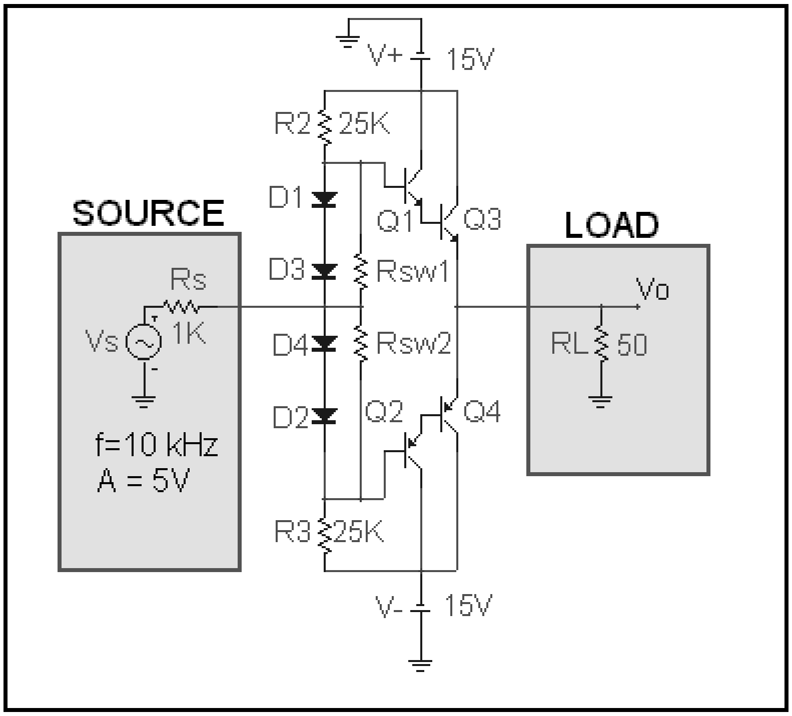
Run the Analysis.



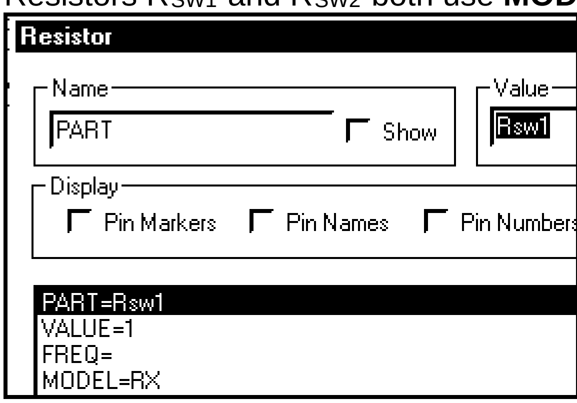
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

Exp 3.7 Comparison of Circuit With and Without Diodes

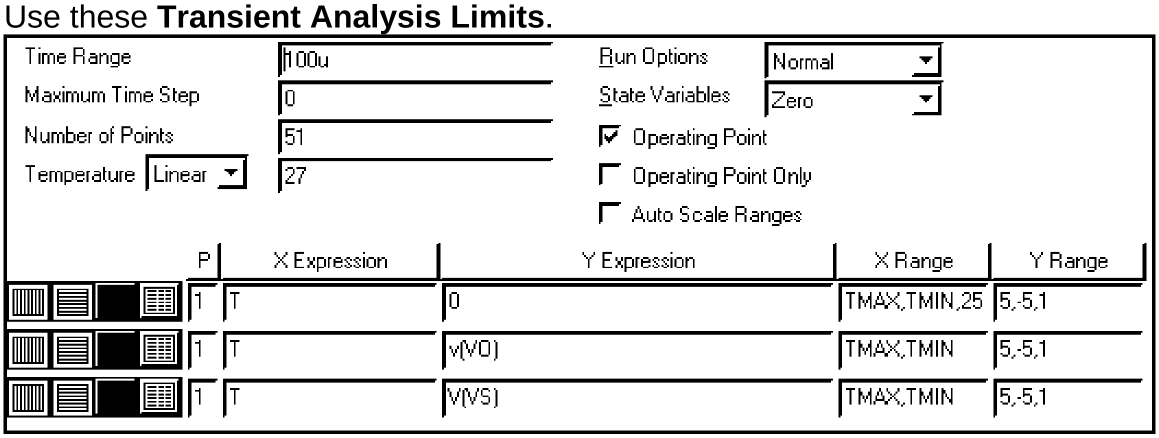
Add resistors R_{SW1} and R_{SW2} to the circuit in the simulation.



Resistors R_{SW1} and R_{SW2} both use **MODEL=RX**.

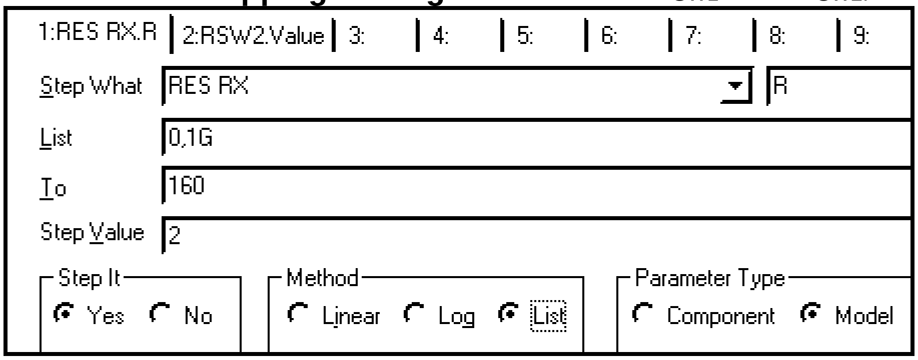


Use these **Transient Analysis Limits**.



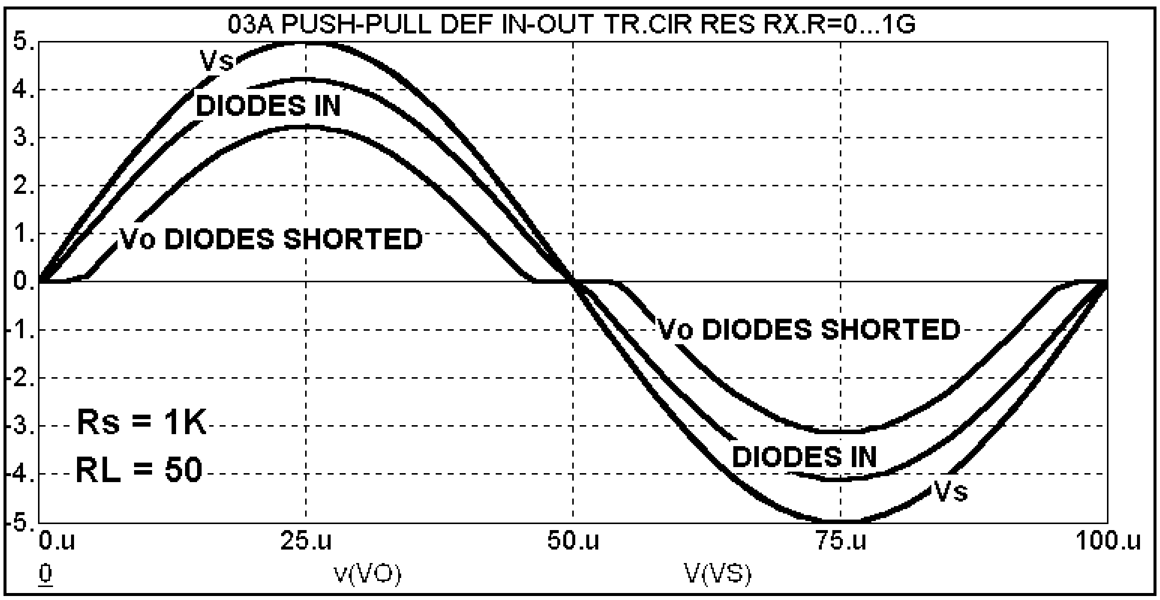
PUSH-PULL CIRCUITS Using Darlington Emitter-Followers EXPERIMENT 3.7

Here are the **Stepping Settings** for resistors R_{SW1} and R_{SW2}.



The value of RX will be step between 0 and 1G. This will result in resistors being stepped between 0 (i.e. a short-circuit) and 1GΩ (= 1000 MΩ), which is essentially an open circuit.

Run the Analysis.

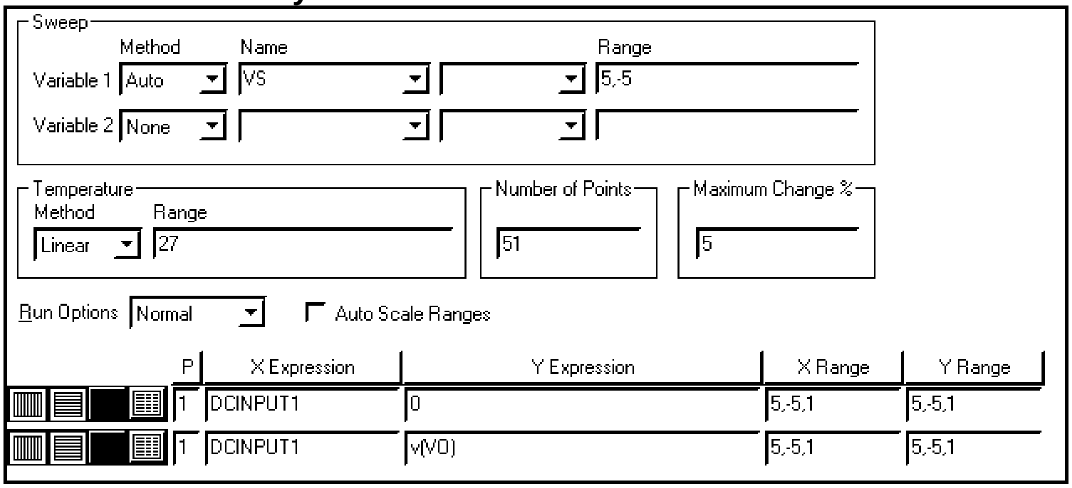


Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

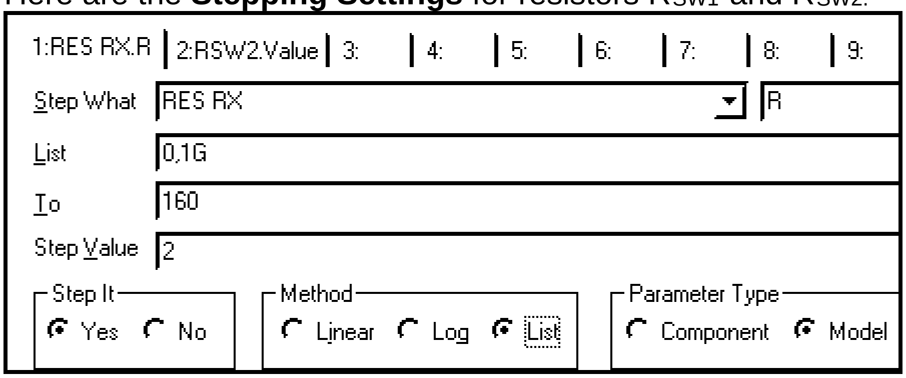
PUSH-PULL CIRCUITS Using Darlington Emitter-Followers EXPERIMENT 3.8

Exp 3.8 Comparison of Circuit With and Without Diodes – Voltage Transfer Curves

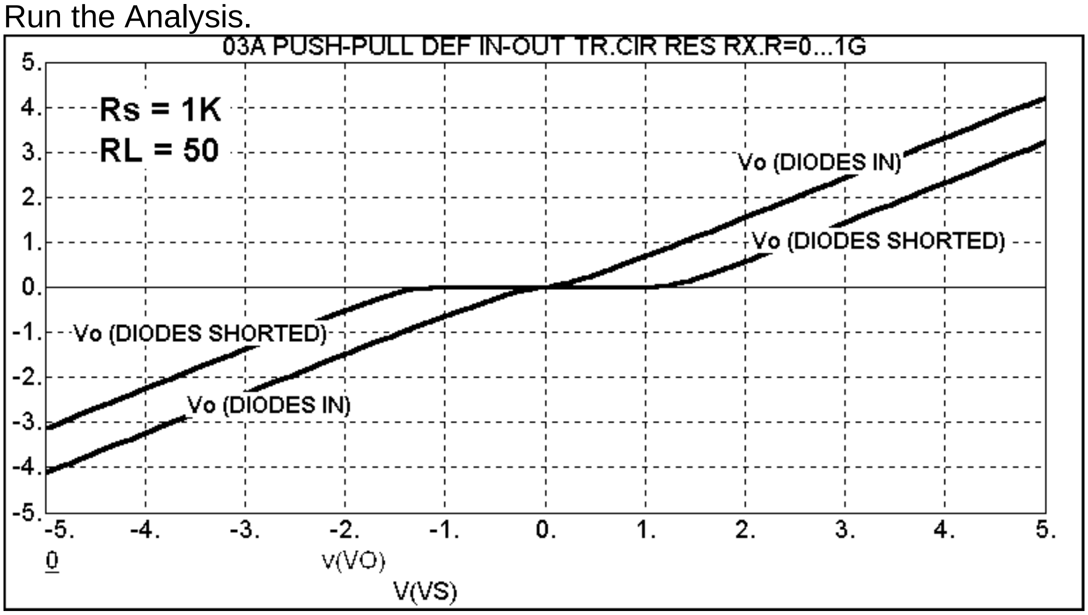
Use these **D-C Analysis Limits**.



Here are the **Stepping Settings** for resistors R_{SW1} and R_{SW2}.



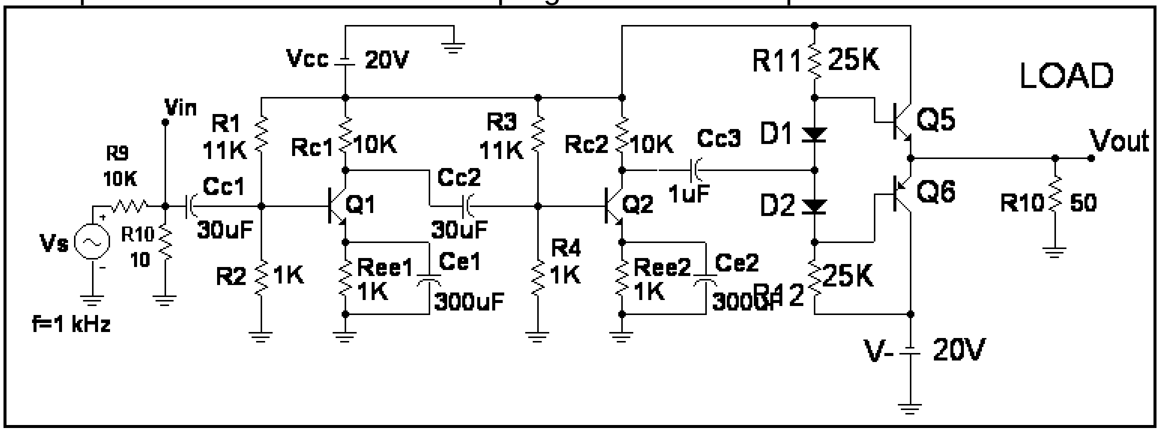
Run the Analysis.



Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

Exp 3.9 Amplifier with Push-Pull Circuit Output Stage

Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis Limits**.

Time Range	2m	Run Options	Normal
Maximum Time Step	2u	State Variables	Zero
Number of Points	50	☑ Operating Point	
Temperature Linear	27	☐ Operating Point Only	
		☐ Auto Scale Ranges	

P	X Expression	Y Expression	X Range	Y Range
1	T	V(Vout)	TMAX,TMIN,,2	5,-5,1
1	T	0	TMAX,TMIN,,2	5,-5,1

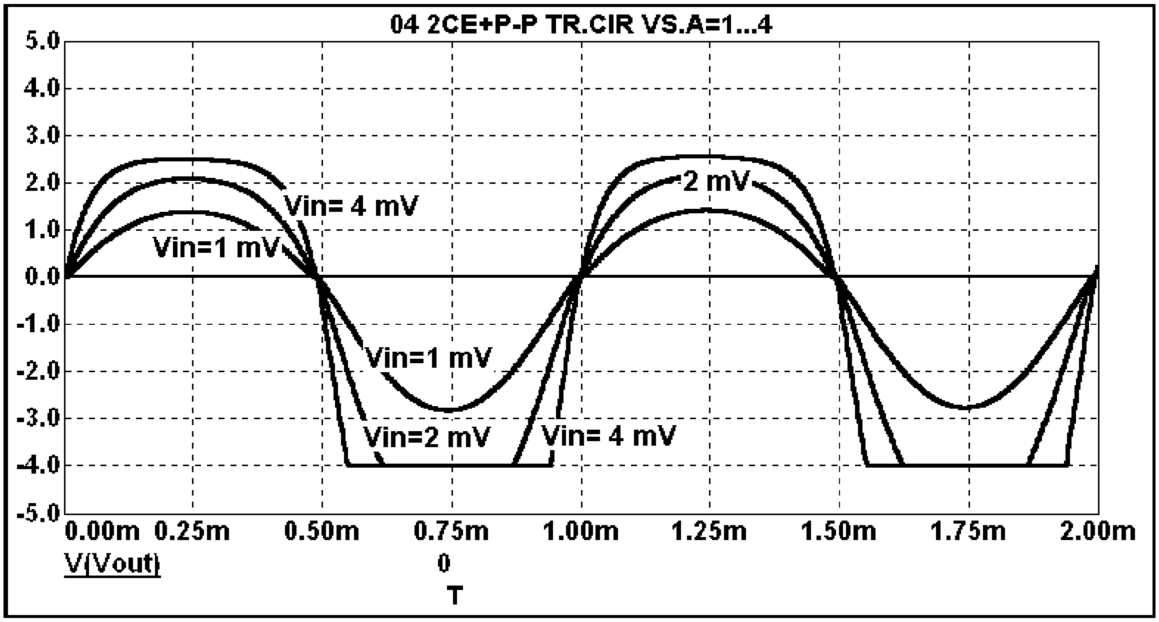
Here are the **Stepping Settings**.

1:VS.A | 2: | 3: | 4: | 5: | 6: | 7: | 8: | 9: | 10: | 11

Step What	VS	A
From	1V	
To	4V	
Step Value	2	

Step It: (•) Yes ( ) No — Method: ( ) Linear (•) Log ( ) List — Parameter Type: (•) Component ( ) Model

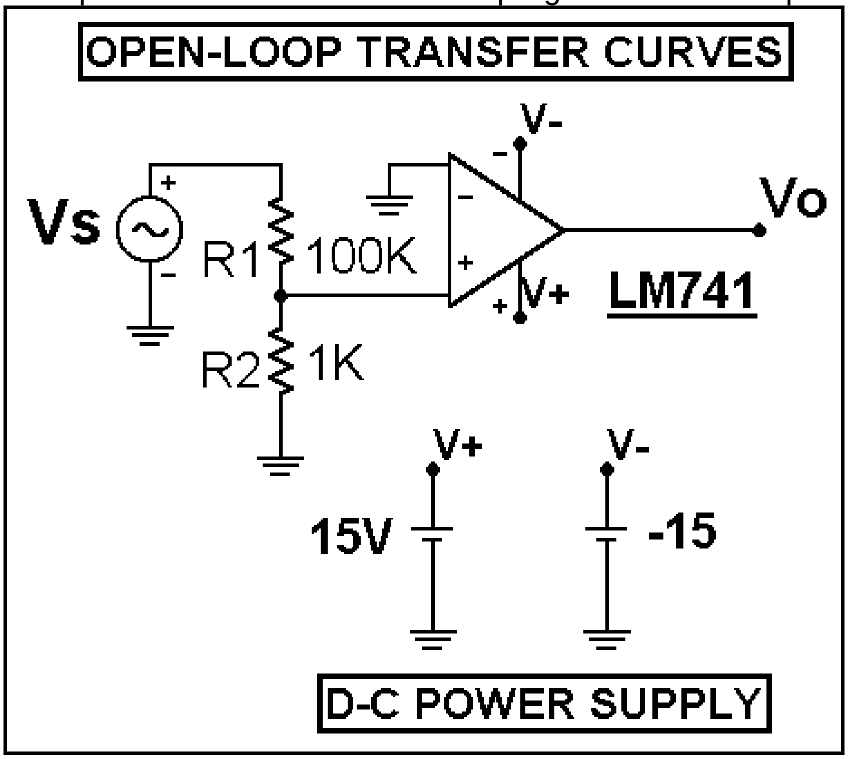
Run the Analysis.



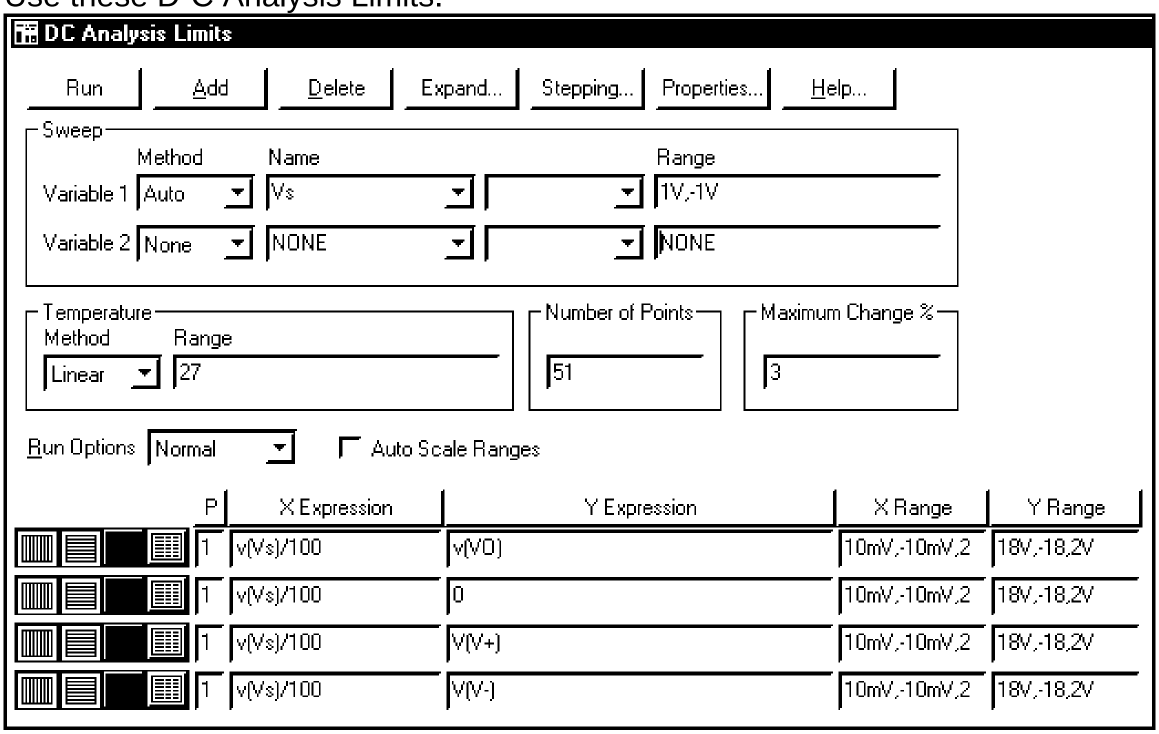
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. Note that V_{IN} is equal to V_S times the R_9-R_{10} voltage division ratio, which in this example is 1/1000.

Exp 4.1: Open-Loop Transfer Curves

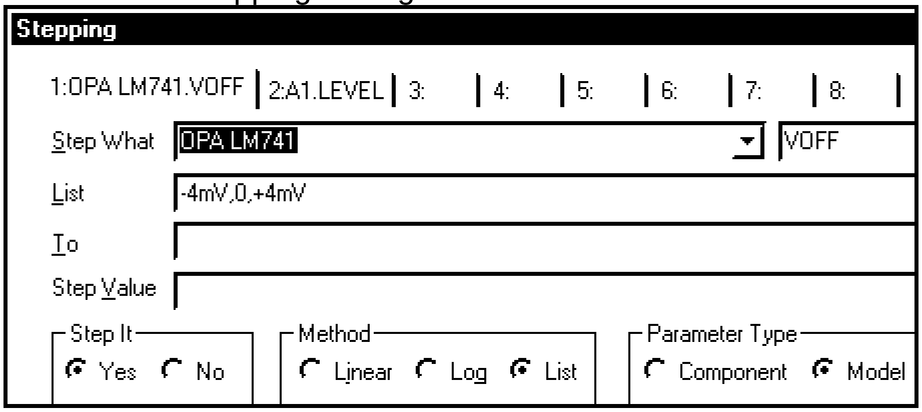
Set up this circuit in the simulation program and on the proto-board.



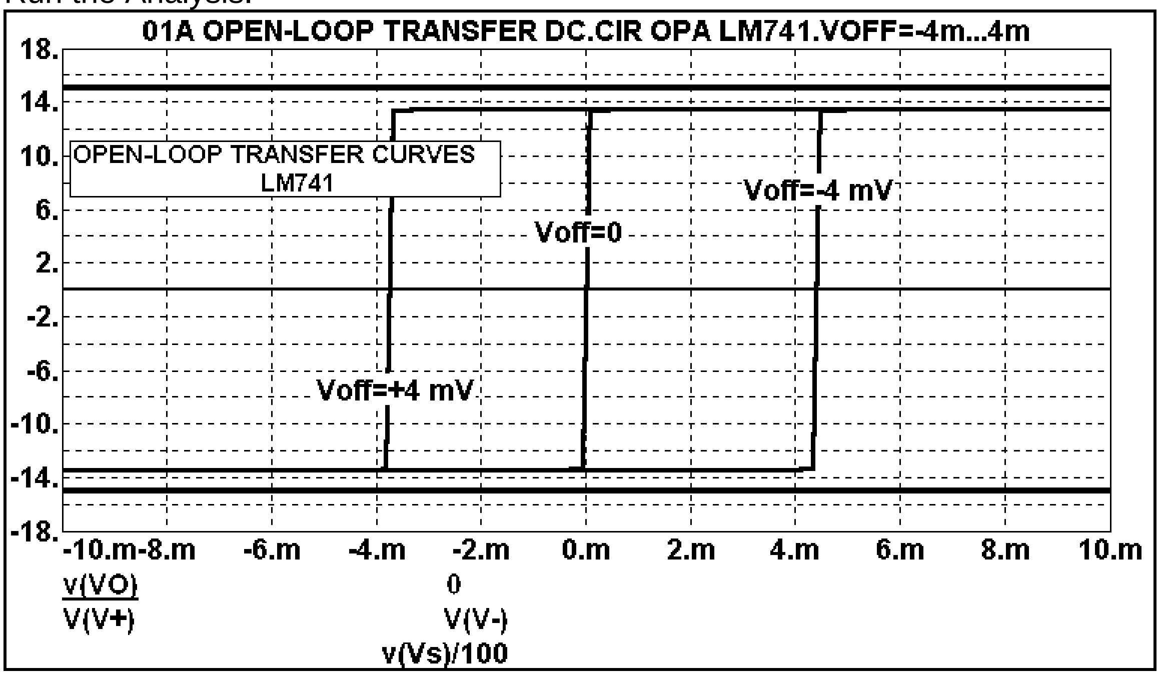
Use these D-C Analysis Limits.



Here are the stepping settings:



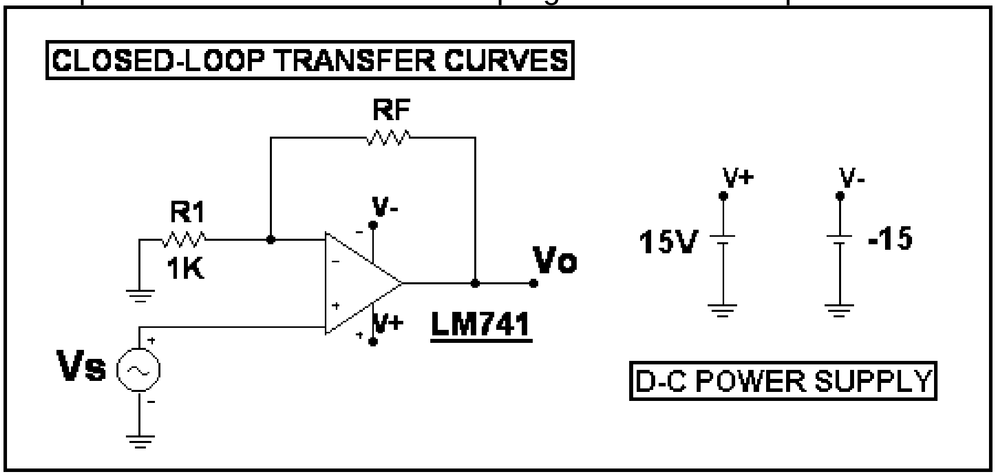
Run the Analysis.



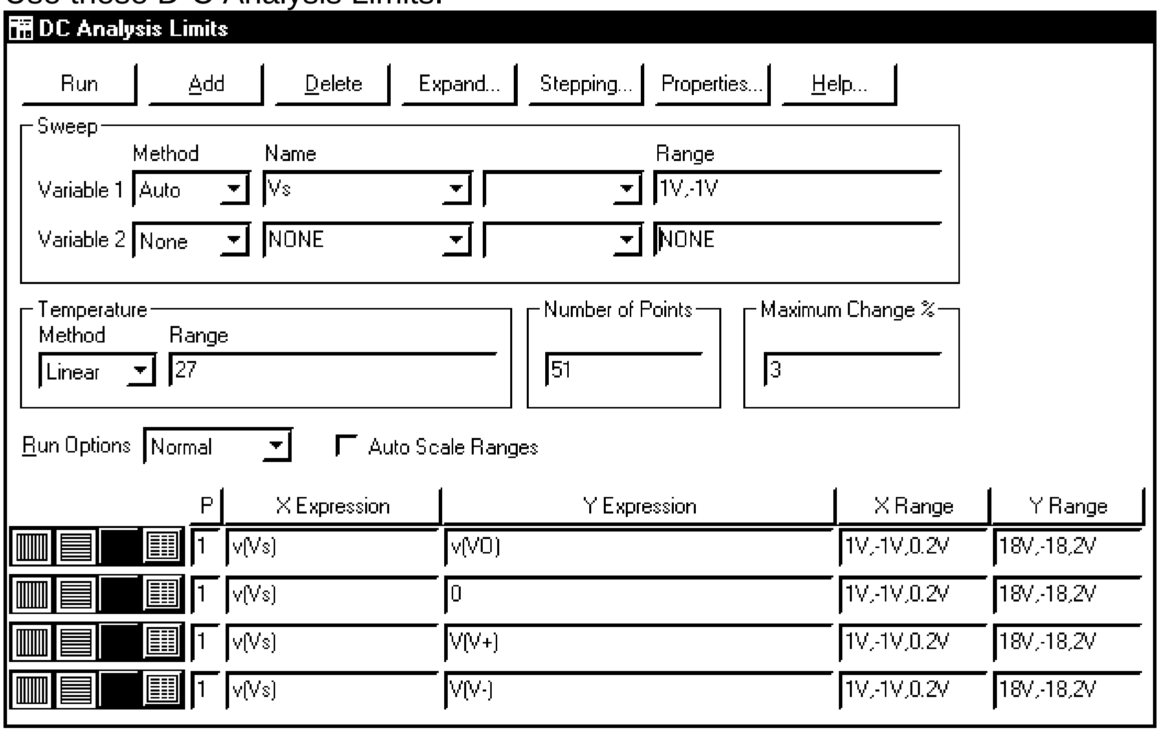
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

Exp 4.2 : Closed-Loop Transfer Curves

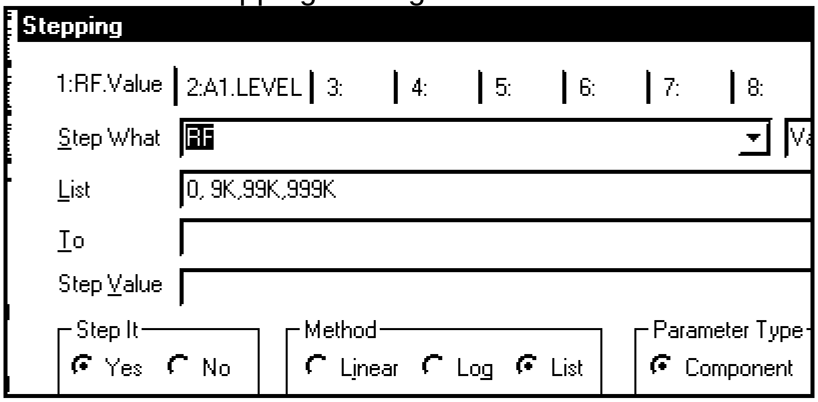
Set up this circuit in the simulation program and on the proto-board.



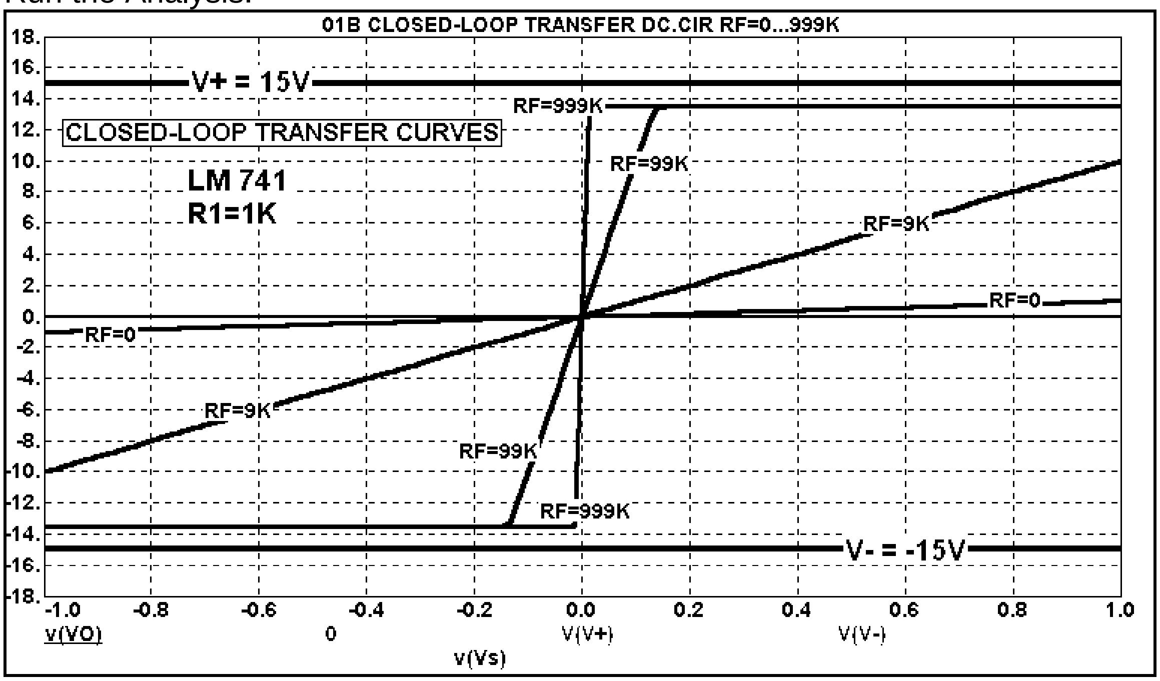
Use these D-C Analysis Limits.



Here are the Stepping Settings.



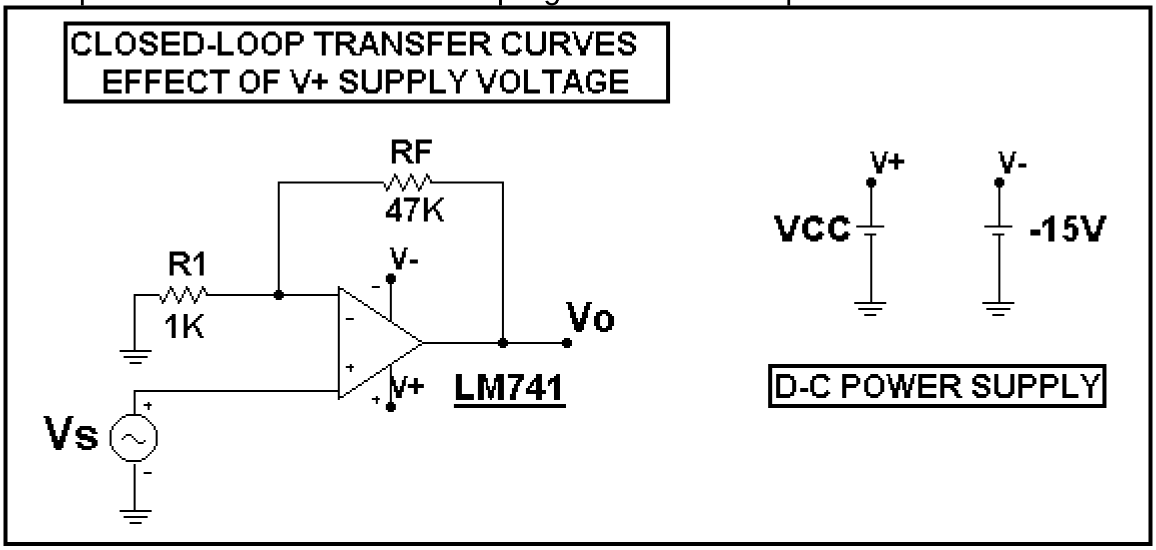
Run the Analysis.



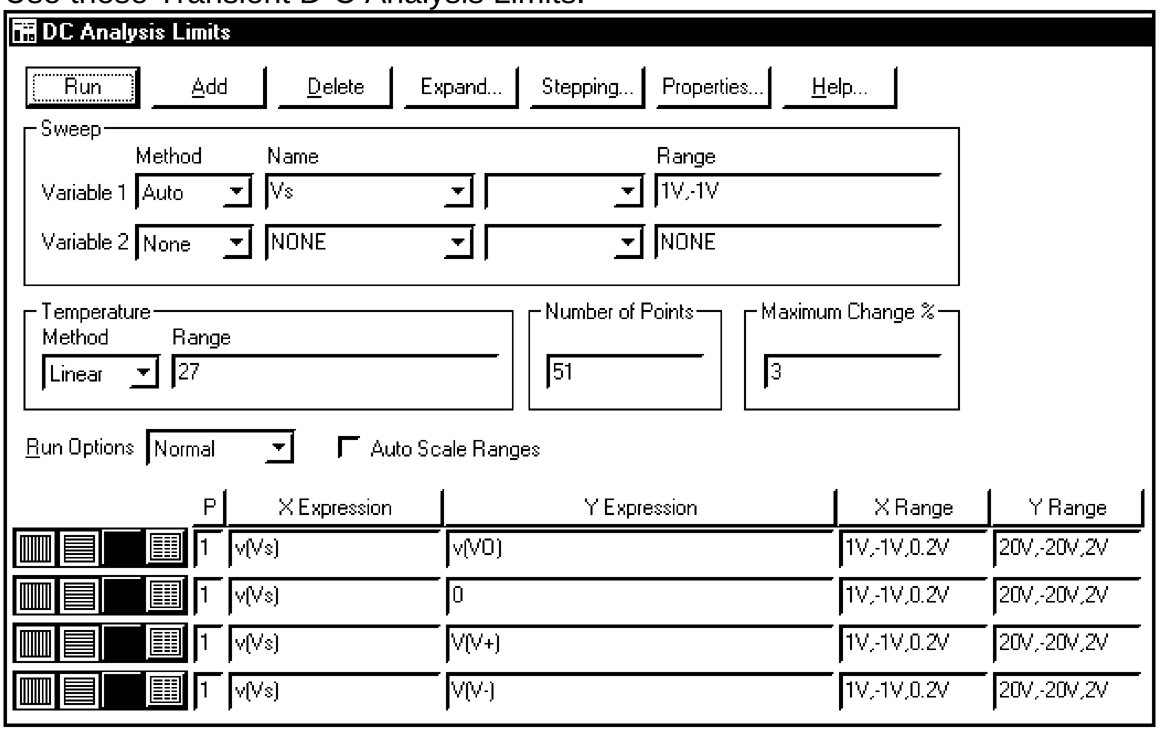
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. Compare the closed-loop gain with the expected value of $\mathbf{A_{CL} = 1 + (R_F/R_1)}$.

Exp 4.3 Closed-Loop Transfer Curves Effect of V+ Supply Voltage

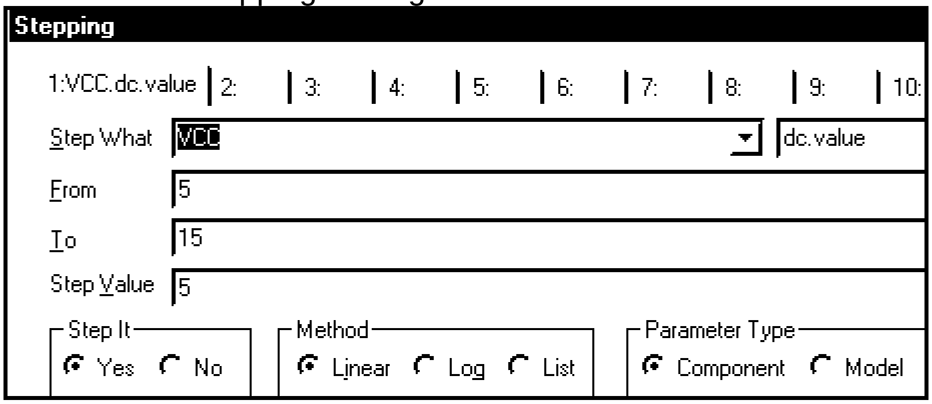
Set up this circuit in the simulation program and on the proto-board.



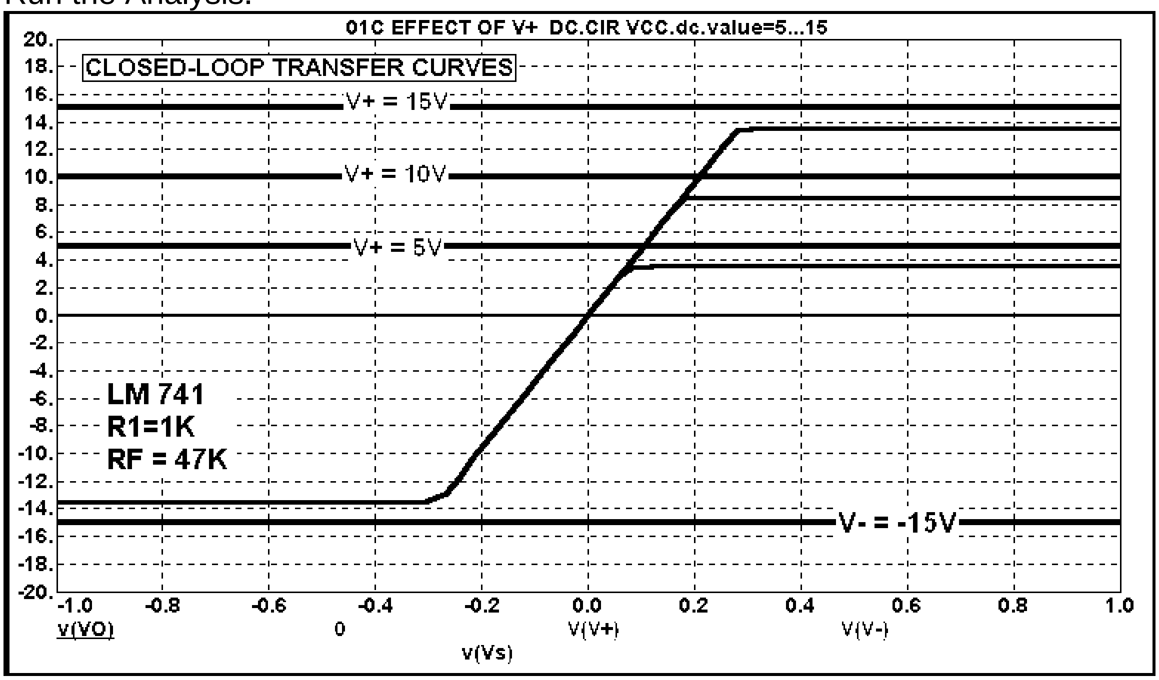
Use these Transient D-C Analysis Limits.



Here are the Stepping Settings.



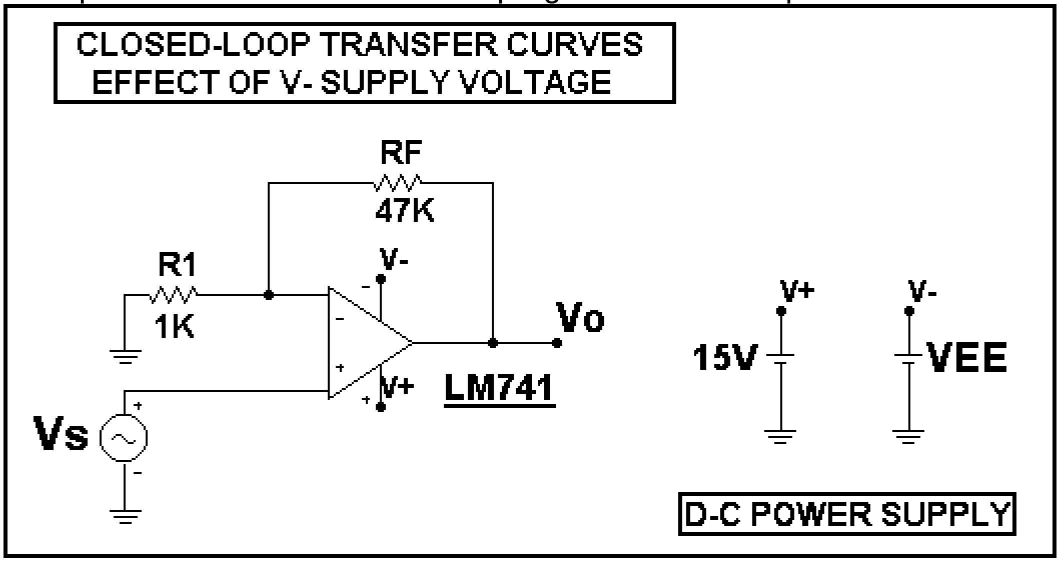
Run the Analysis.



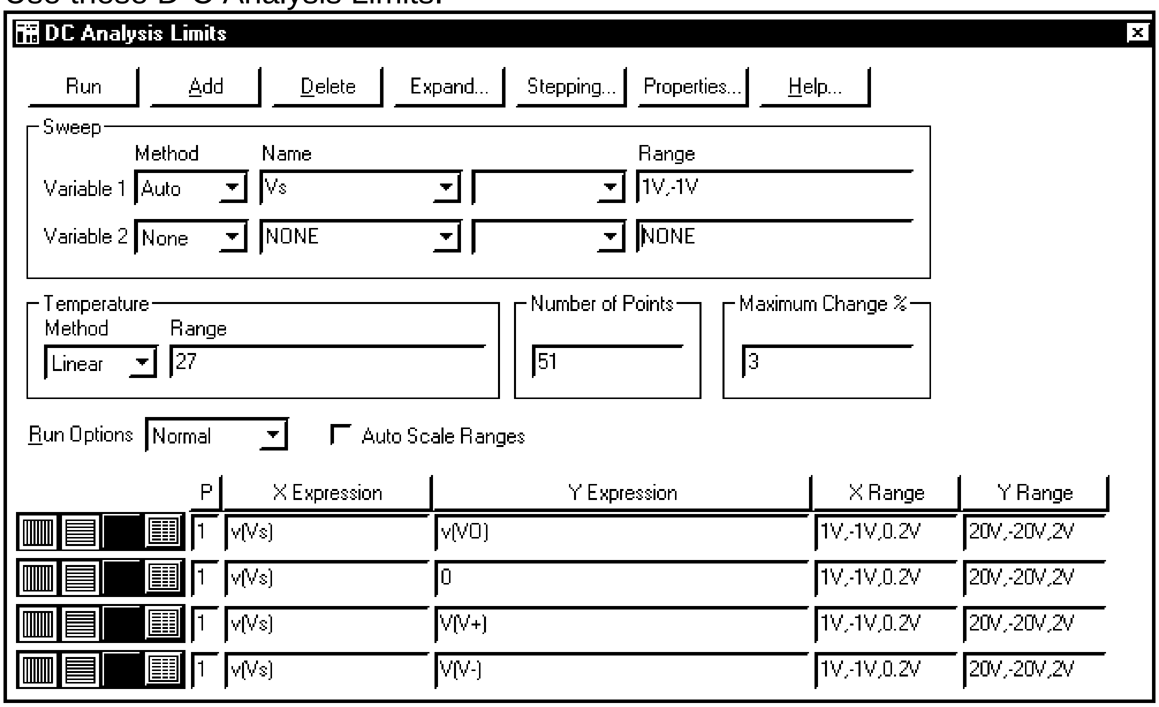
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

Exp 4.4 Closed-Loop Transfer Curves Effect of V- Supply Voltage

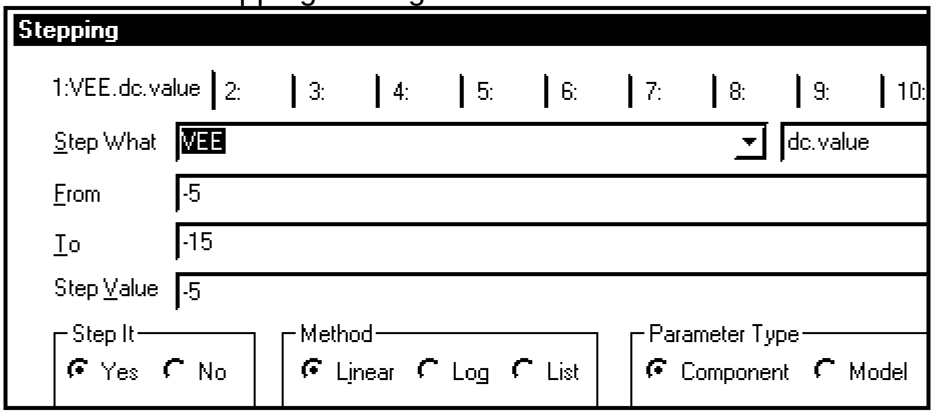
Set up this circuit in the simulation program and on the proto-board.



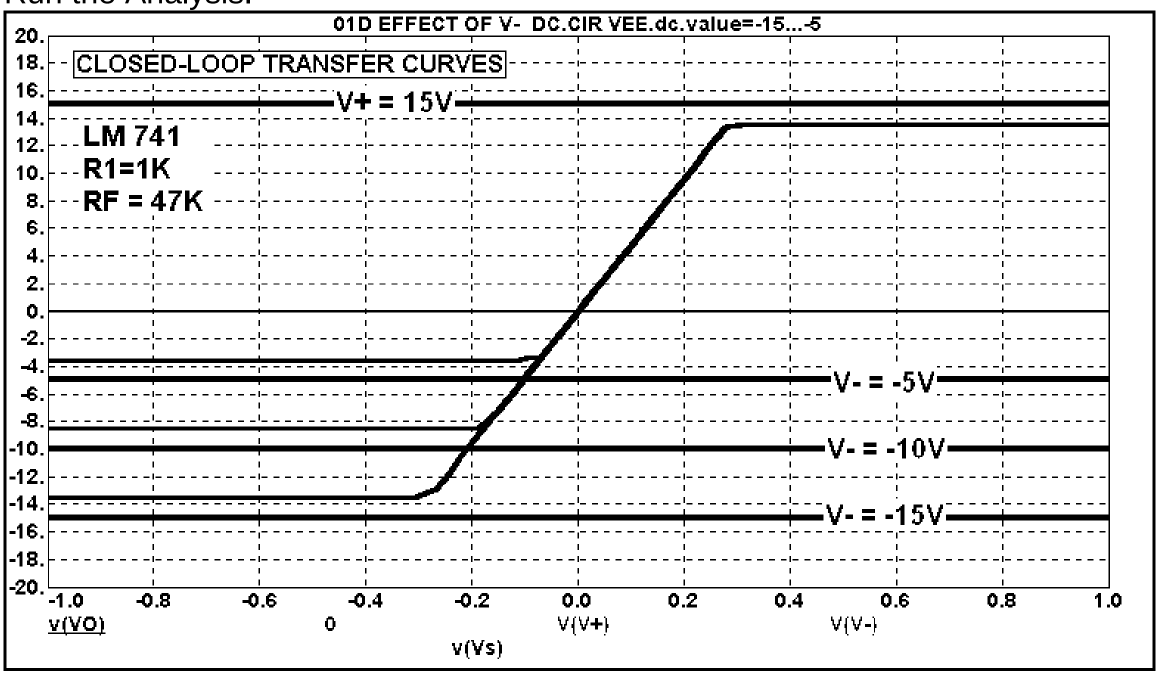
Use these D-C Analysis Limits.



Here are the Stepping Settings.



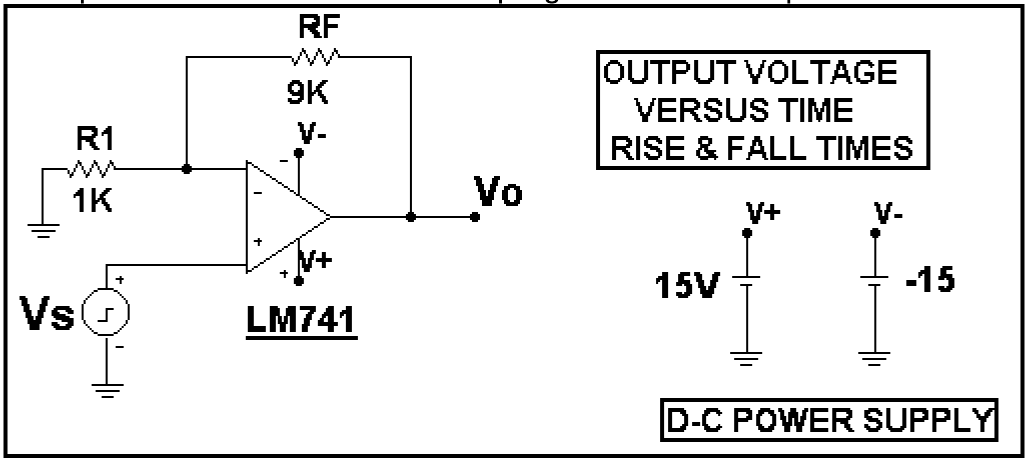
Run the Analysis.



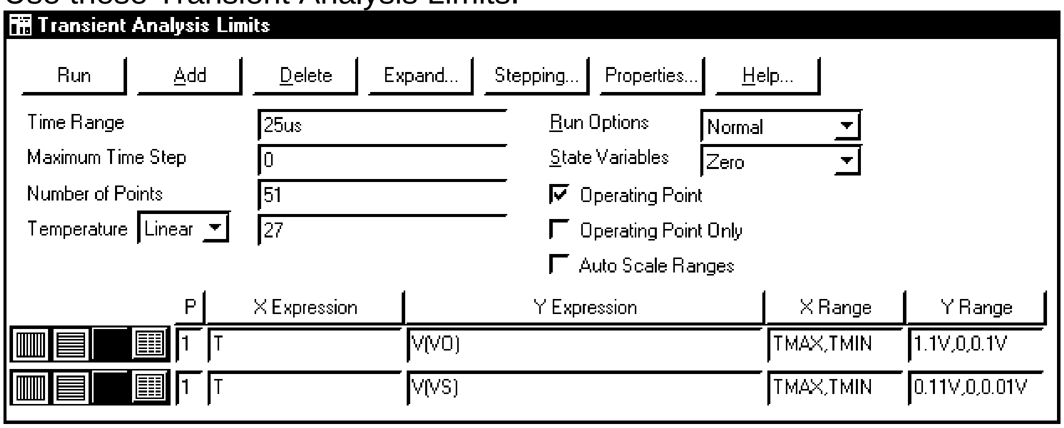
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

Exp 4.5 OUTPUT VOLTAGE VERSUS TIME RISE & FALL TIMES

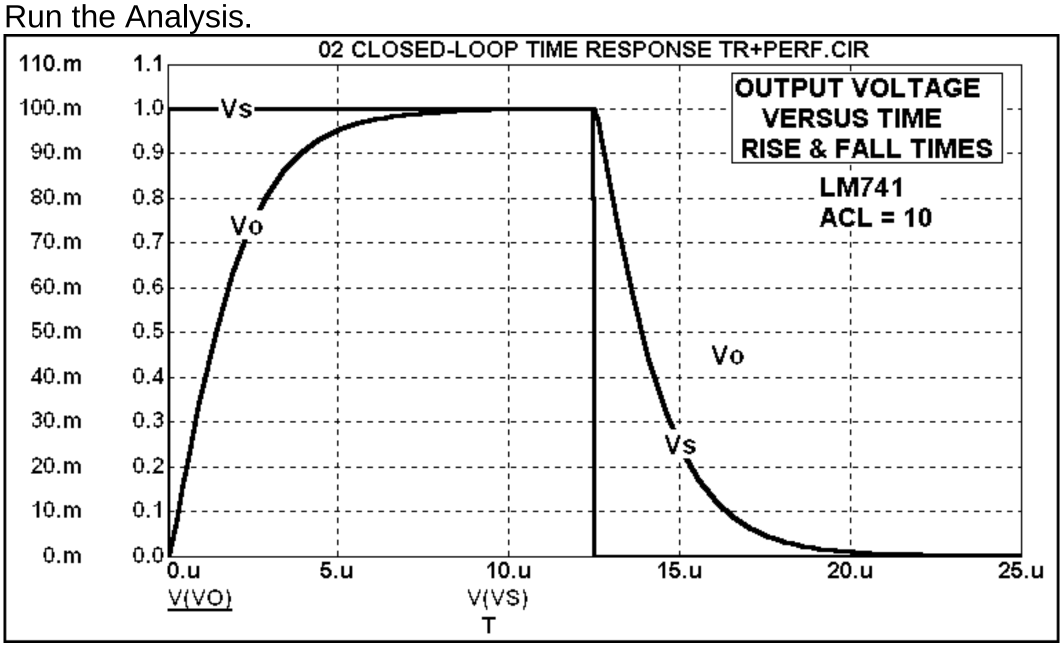
Set up this circuit in the simulation program and on the proto-board.



Use these Transient Analysis Limits.

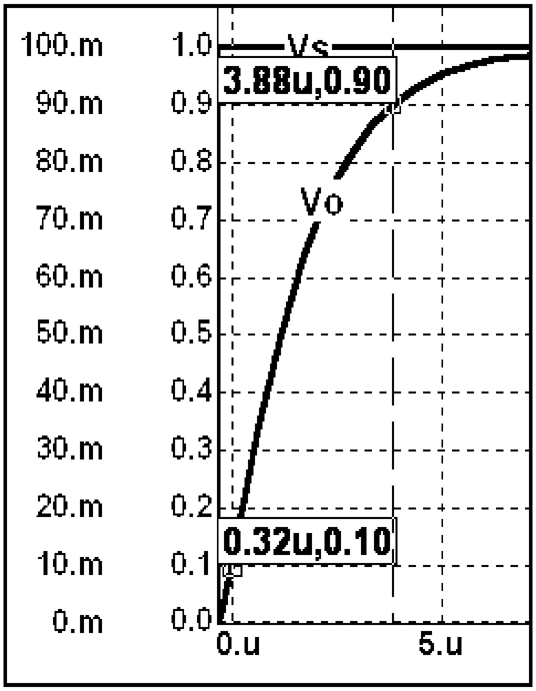


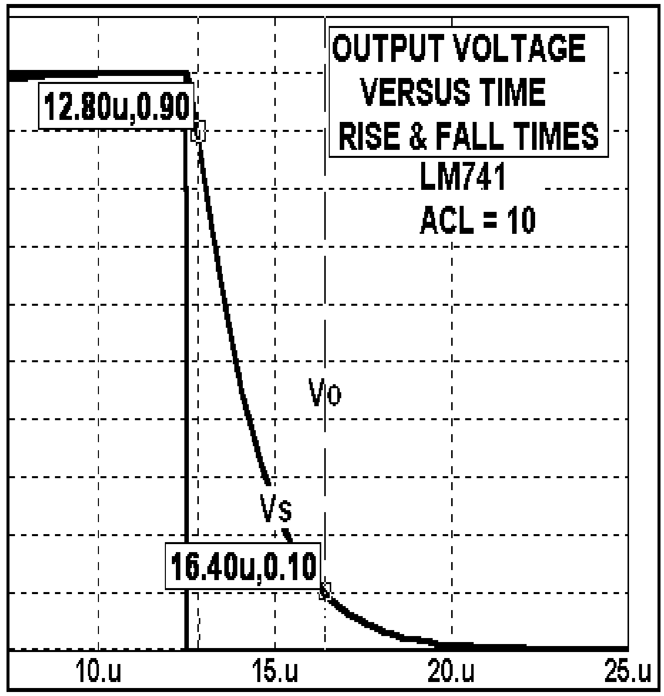
Run the Analysis.



Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

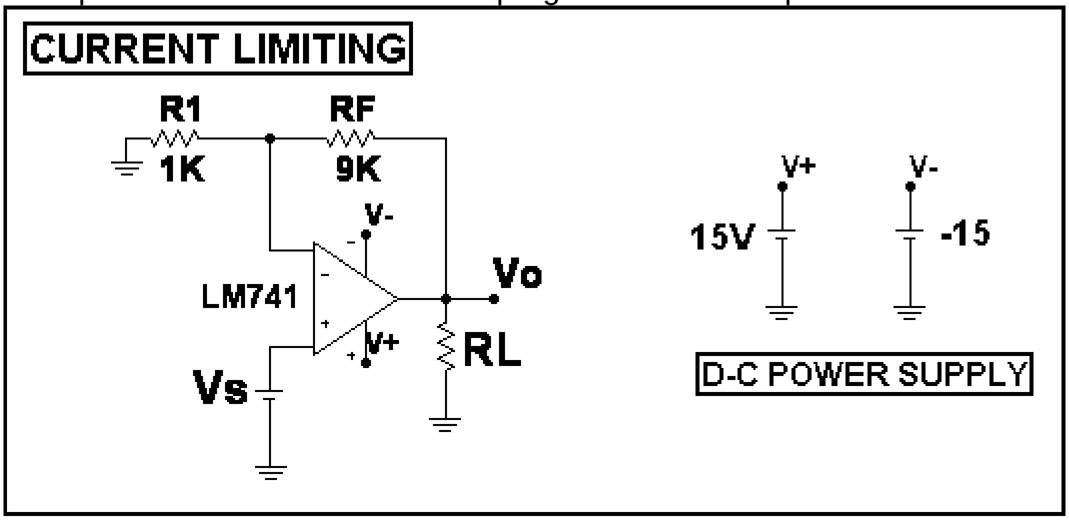
Measure the 10% to 90% Rise Time and the 90% to 10% Fall Time on the circuit and compare with the simulation results as shown below.



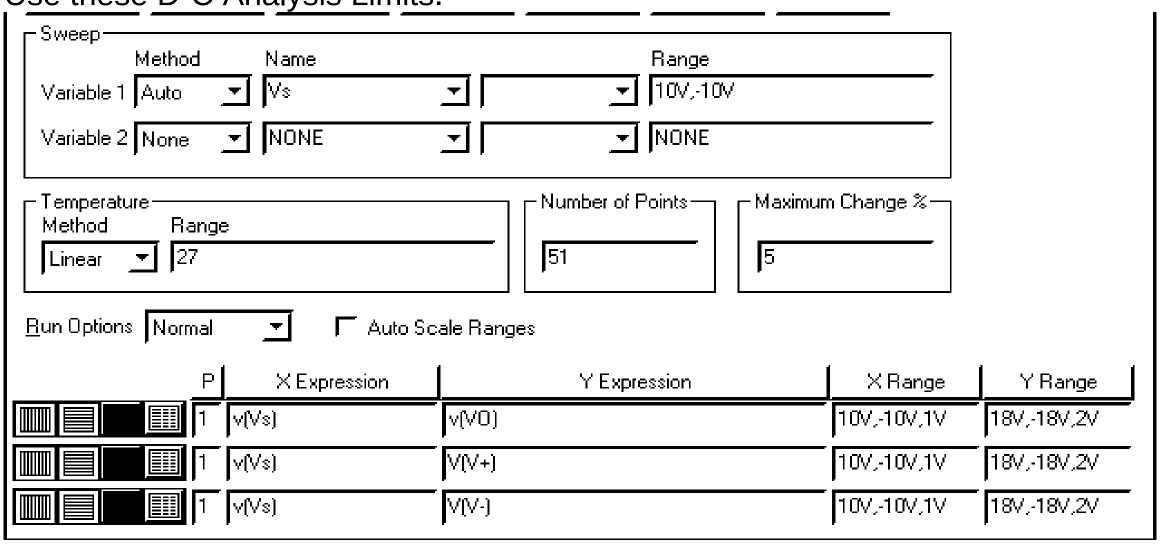


Exp 4.6 Current Limiting

Set up this circuit in the simulation program and on the proto-board.



Use these D-C Analysis Limits.


Sweep

	Method	Name		Range
Variable 1	Auto	Vs		10V,-10V
Variable 2	None	NONE		NONE

Temperature — Method: Linear; Range: 27

Number of Points: 51

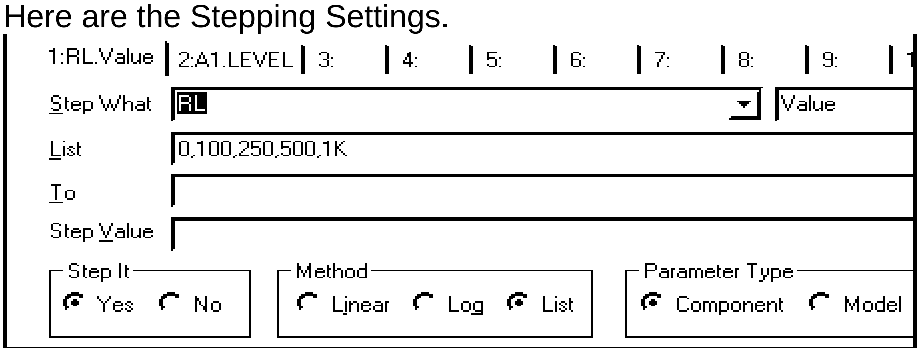
Maximum Change %: 5

Run Options: Normal

Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	v(Vs)	v(VO)	10V,-10V,1V	18V,-18V,2V
1	v(Vs)	V(V+)	10V,-10V,1V	18V,-18V,2V
1	v(Vs)	V(V-)	10V,-10V,1V	18V,-18V,2V

Here are the Stepping Settings.


1:RL.Value | 2:A1.LEVEL | 3: | 4: | 5: | 6: | 7: | 8: | 9: | 1

Step What: RL — Value

List: 0,100,250,500,1K

To:

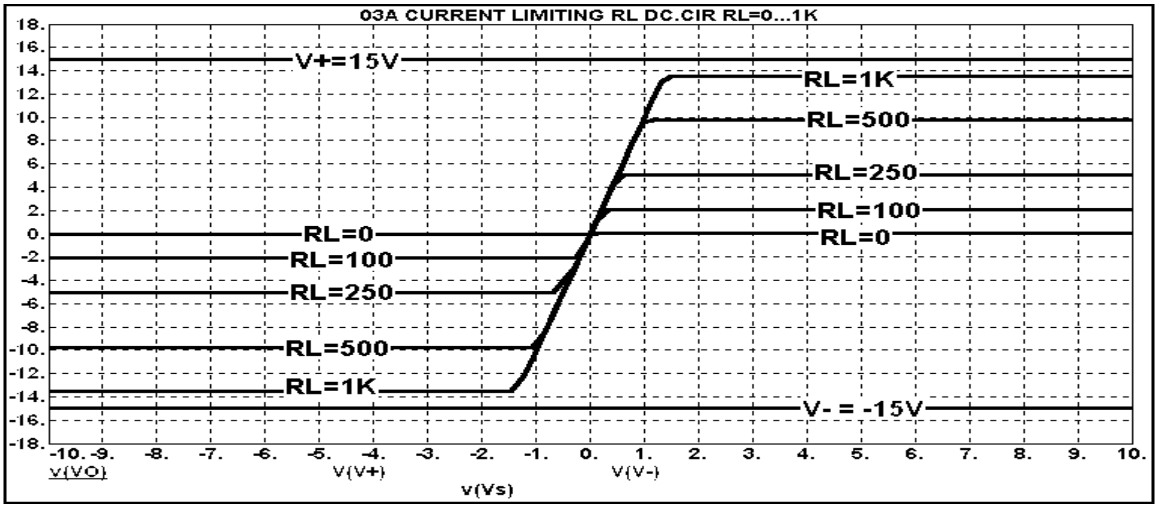
Step Value:

Step It: (•) Yes ( ) No

Method: ( ) Linear ( ) Log (•) List

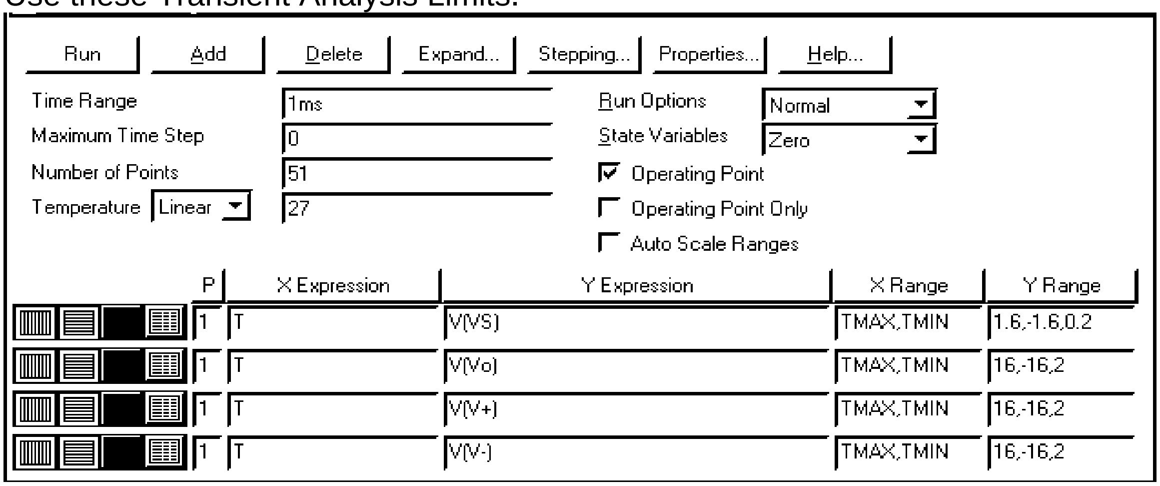
Parameter Type: (•) Component ( ) Model

Run the Analysis.



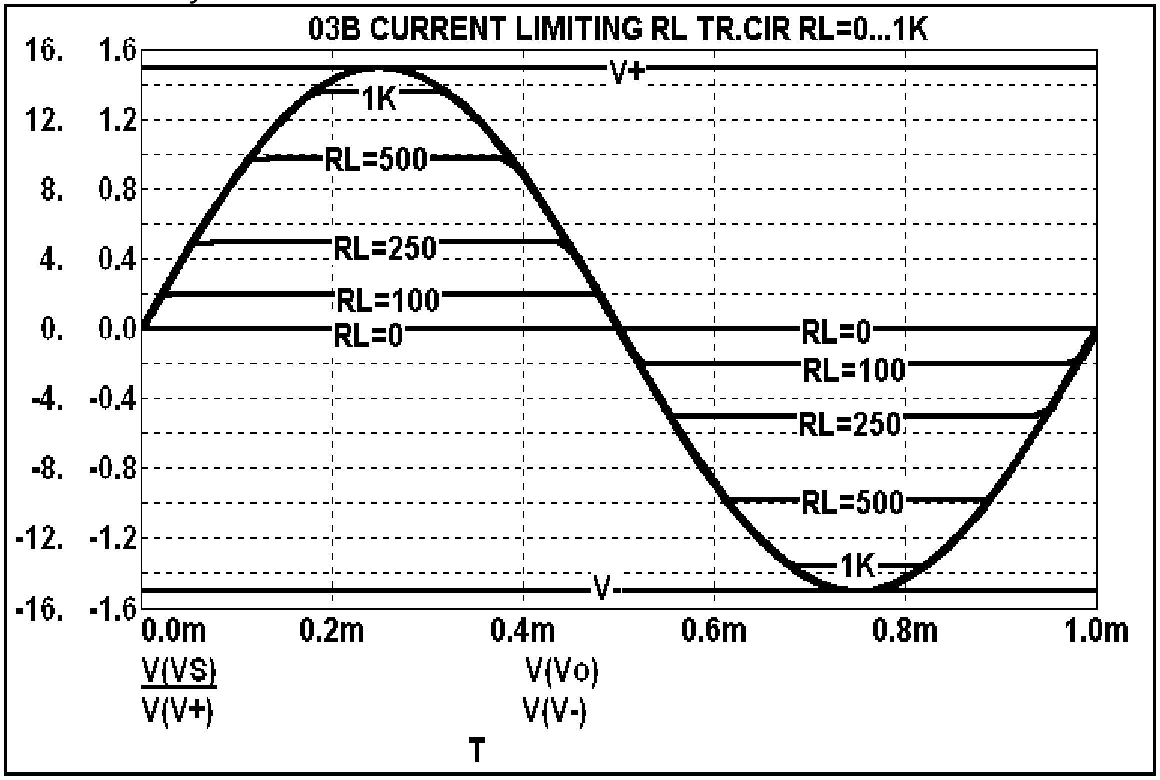
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. The current limit of this operational amplifier is I_{CL} = ± 20 mA. Compare the results with the expected values.

Use these Transient Analysis Limits.



Use the same Stepping Settings as before.

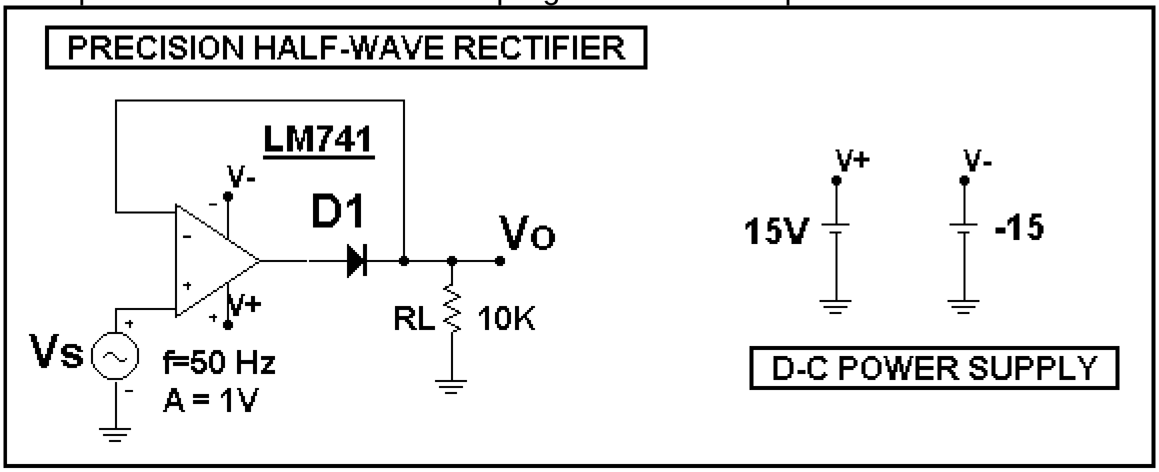
Run the Analysis.



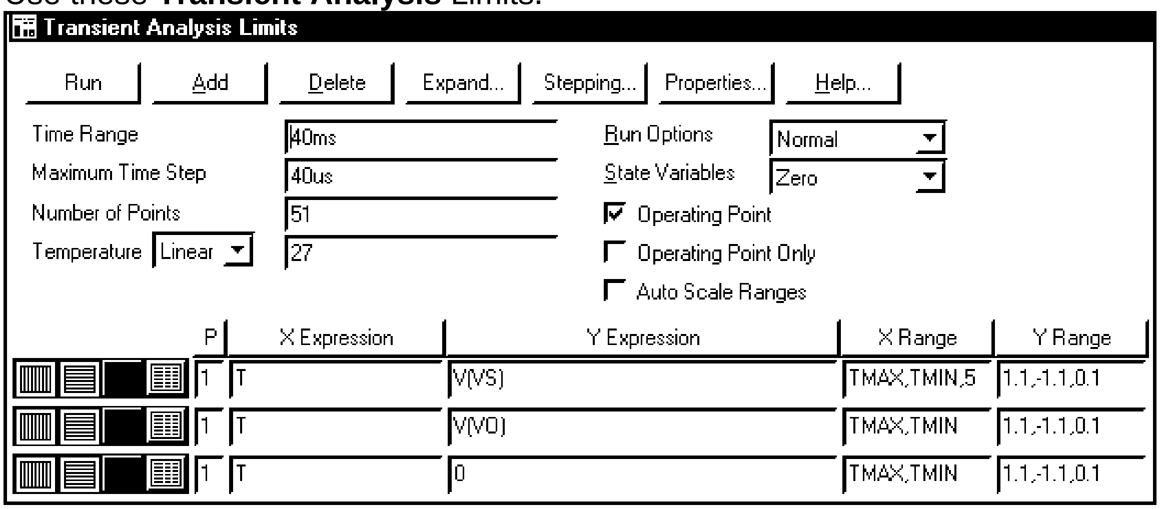
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. . The current limit of this operational amplifier is I_{CL} = ± 20 mA. Compare the results with the expected values.

EXP 4.7 Precision Half-Wave Rectifier

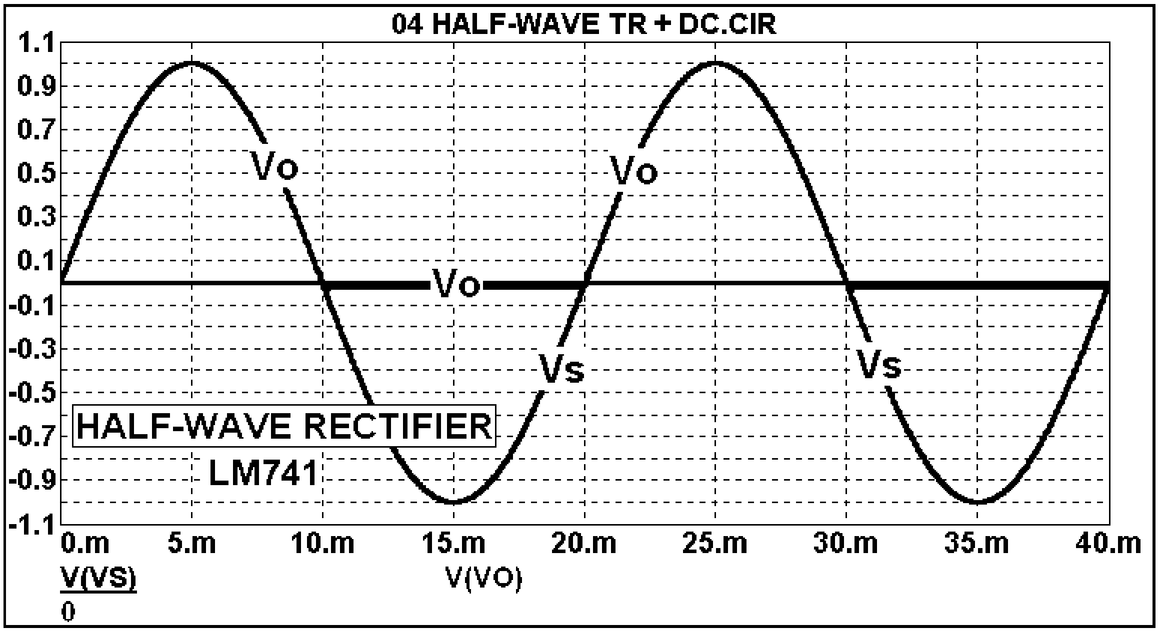
Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis** Limits.

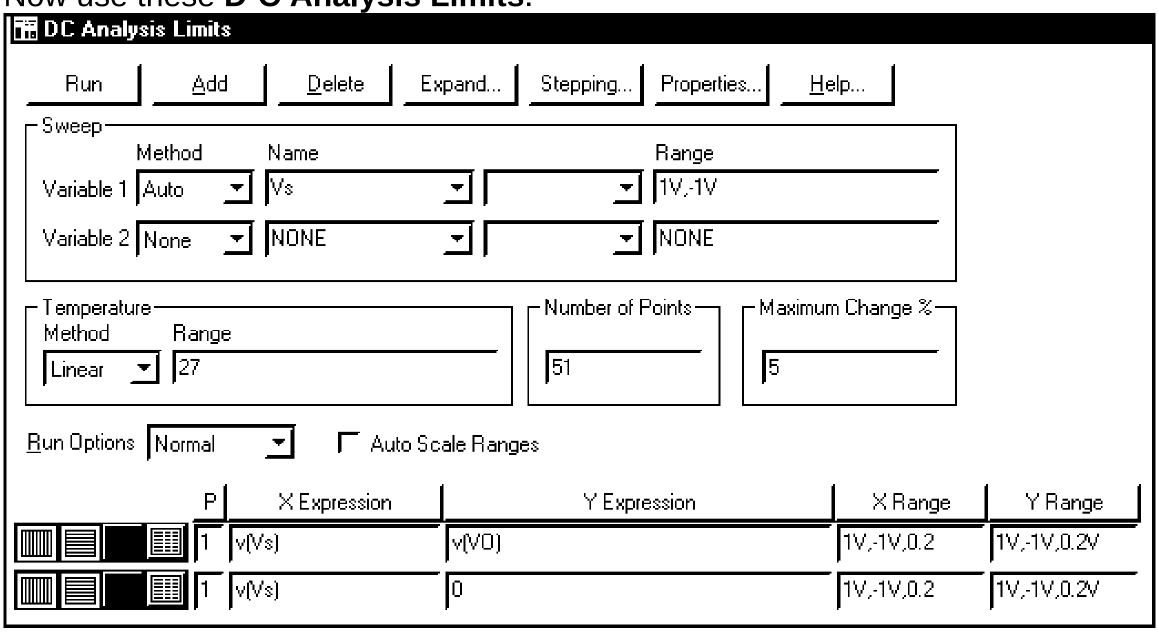


Run the Analysis.

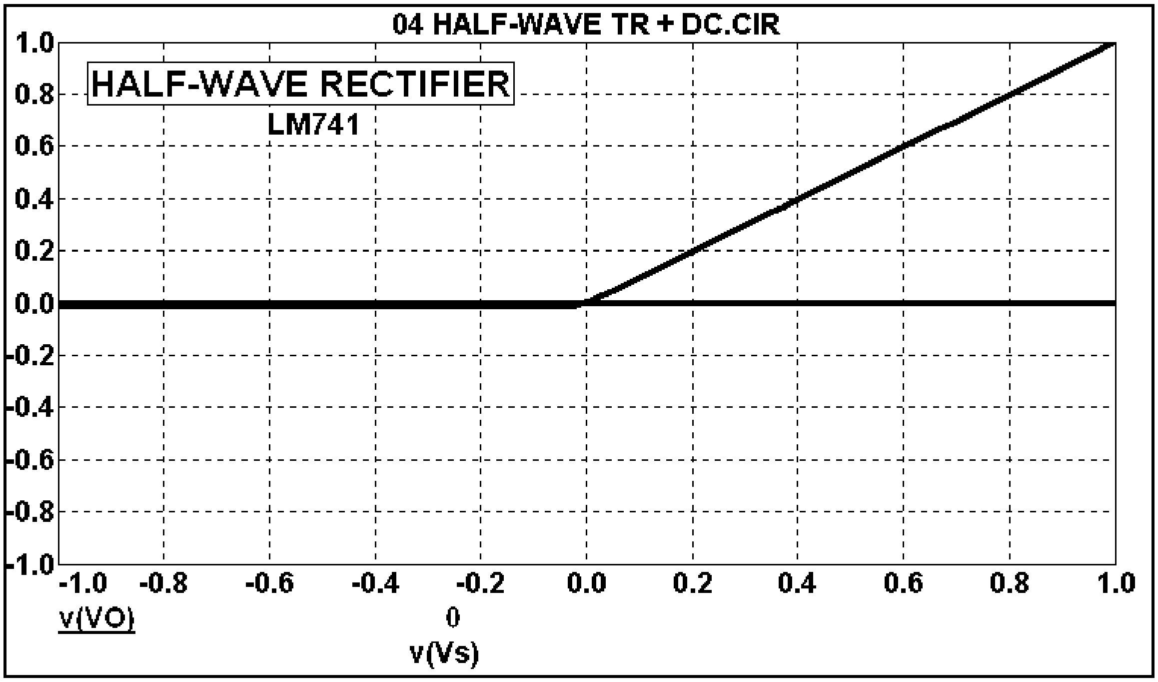


Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. What effect does the diode voltage drop have on this circuit, as compared to a half-wave rectifier that does not use an operational amplifier? Why is this called a **Precision Half-Wave Rectifier**?

Now use these **D-C Analysis Limits**.



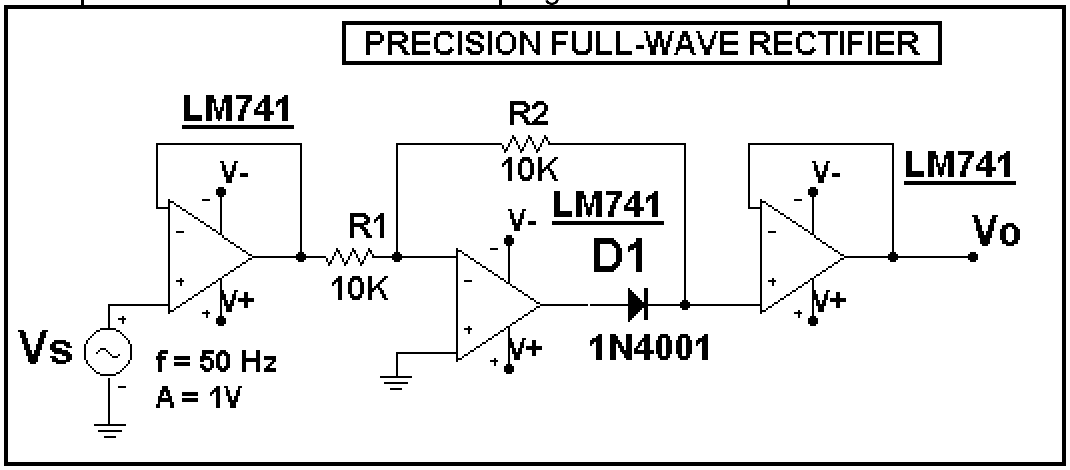
Run the Analysis.



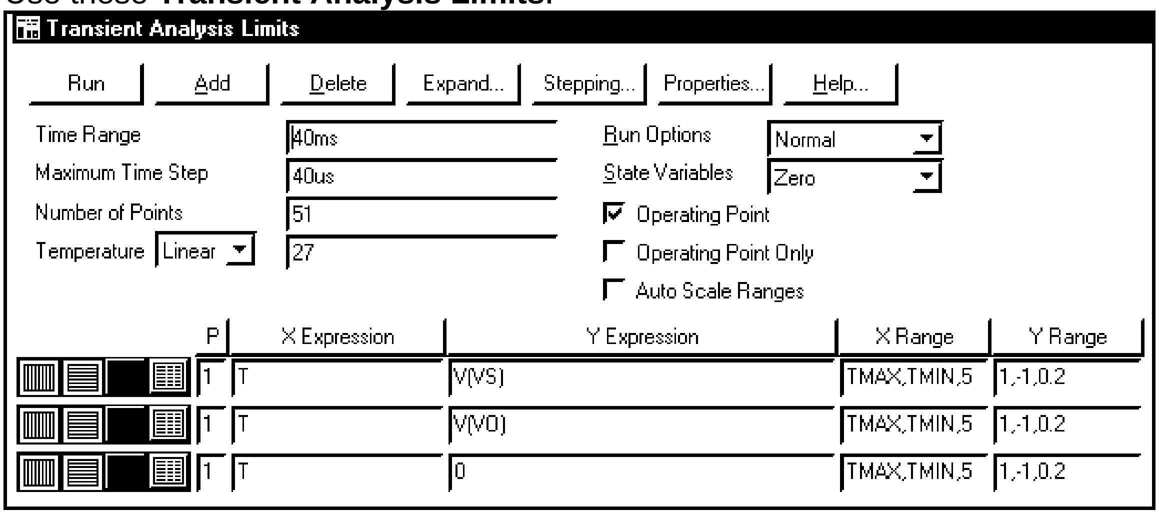
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. What effect does the diode voltage drop have on this circuit, as compared to a half-wave rectifier that does not use an operational amplifier? Why is this called a **Precision Half-Wave Rectifier**?

EXP 4.8 Precision Full-Wave Rectifier

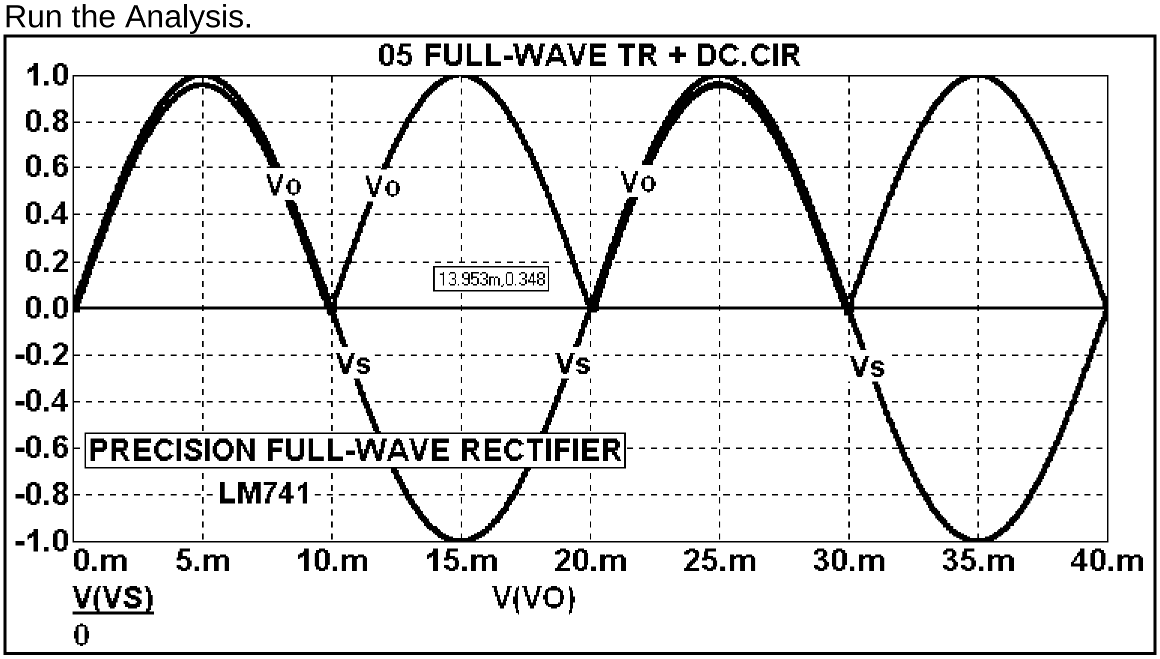
Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis Limits**.

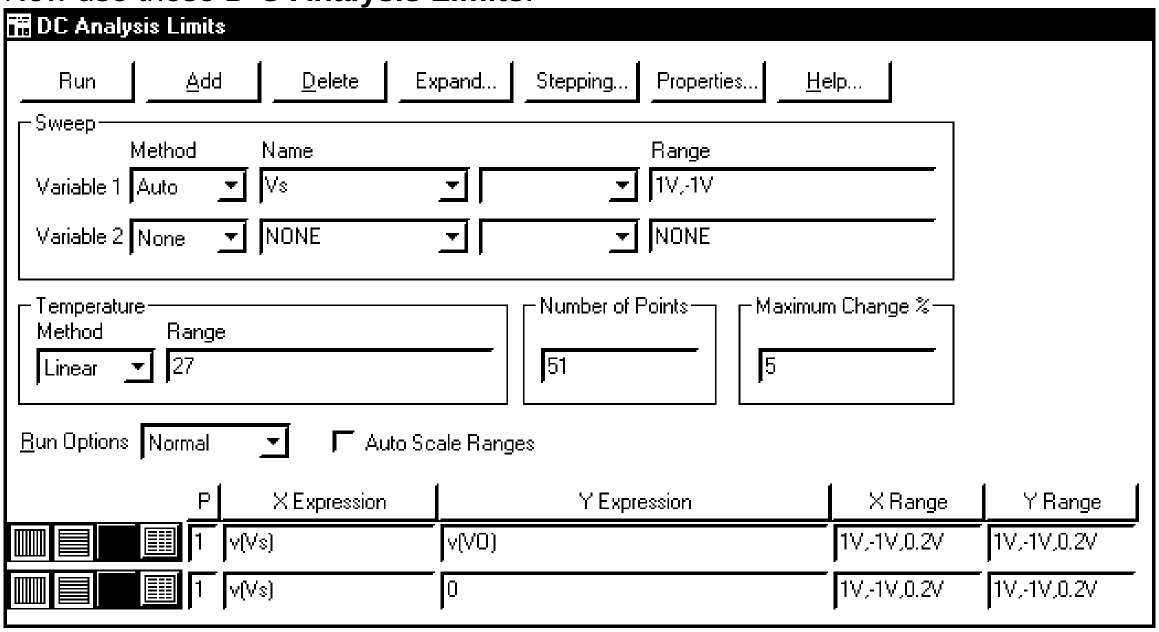


Run the Analysis.

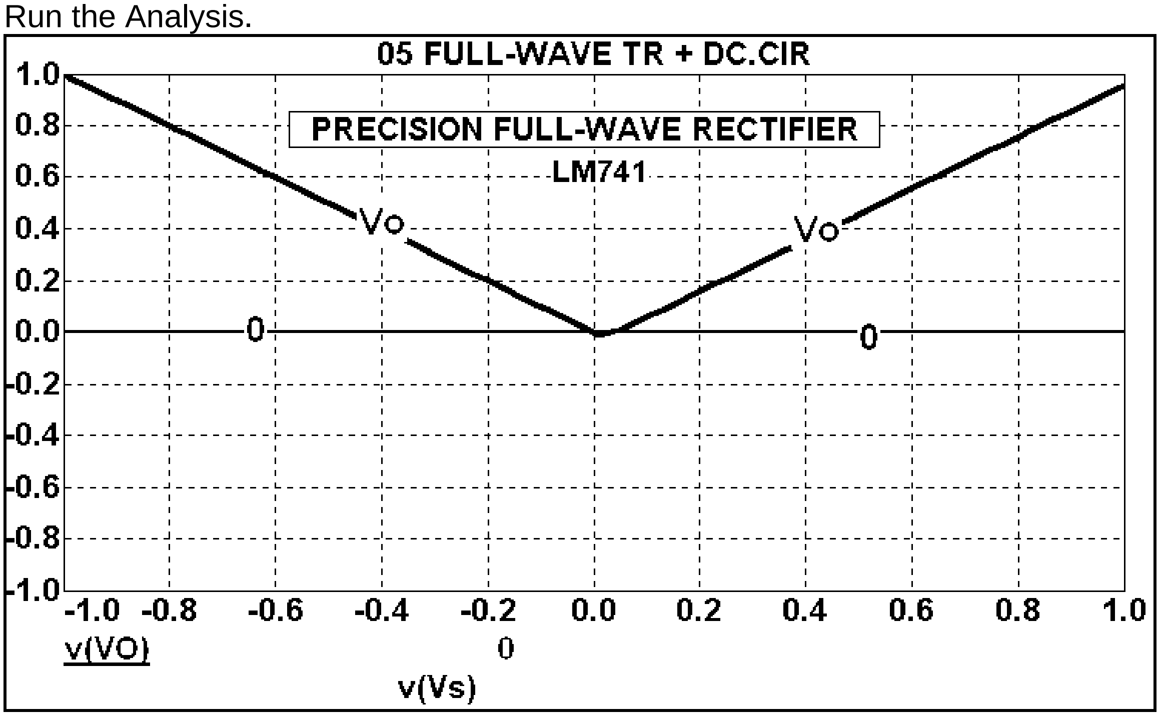


Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. What effect does the diode voltage drop have on this circuit, as compared to a half-wave rectifier that does not use an operational amplifier? Why is this called a **Precision Full-Wave Rectifier**?

Now use these **D-C Analysis Limits**.



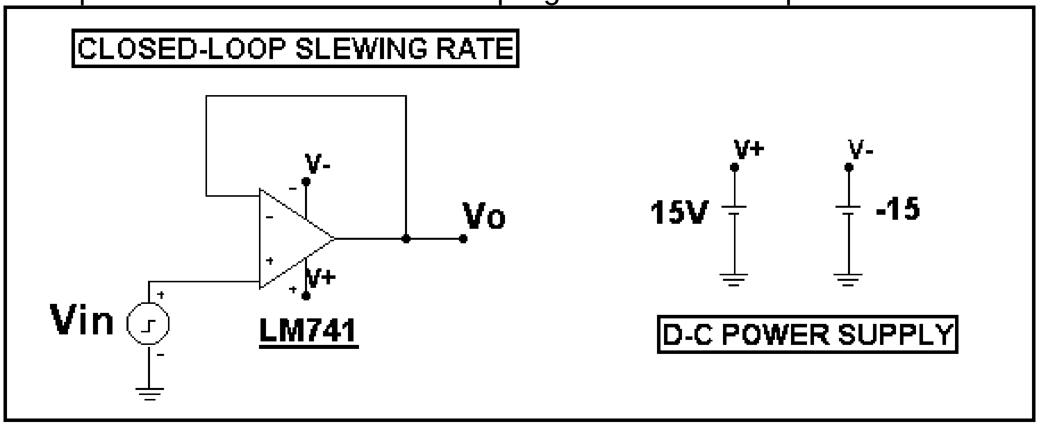
Run the Analysis.



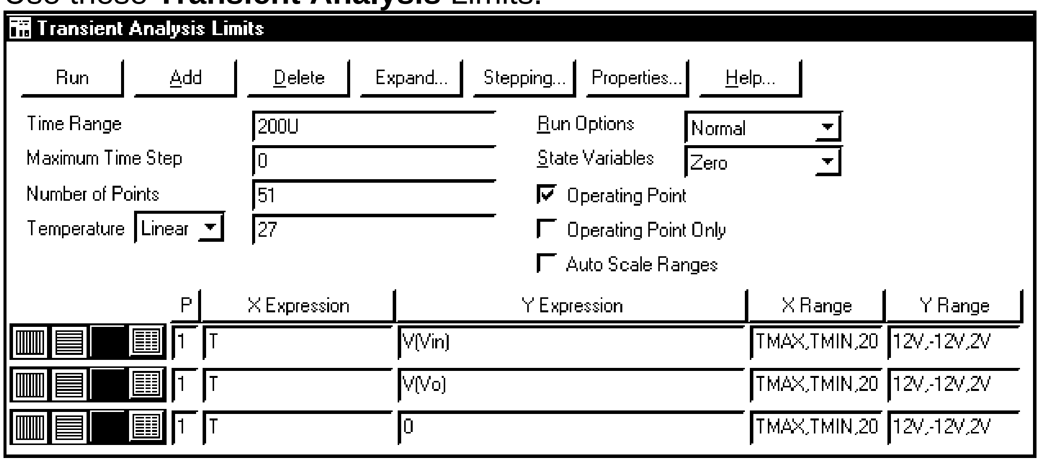
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. What effect does the diode voltage drop have on this circuit, as compared to a half-wave rectifier that does not use an operational amplifier? Why is this called a **Precision Full-Wave Rectifier**?

Exp 4.9 Closed-Loop Slewing Rate – Square-Wave Input

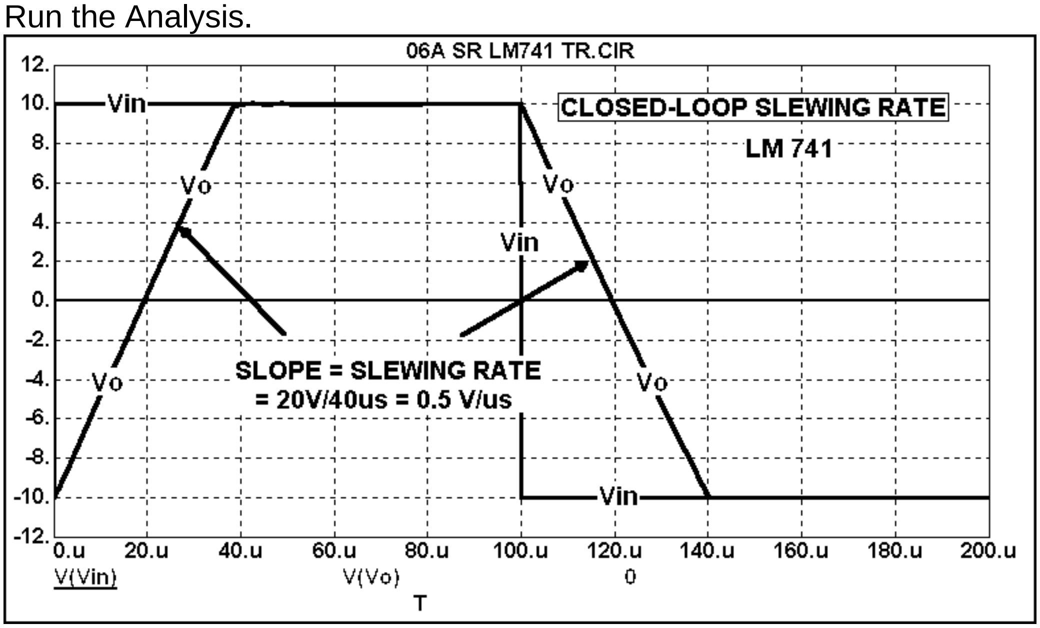
Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis** Limits.



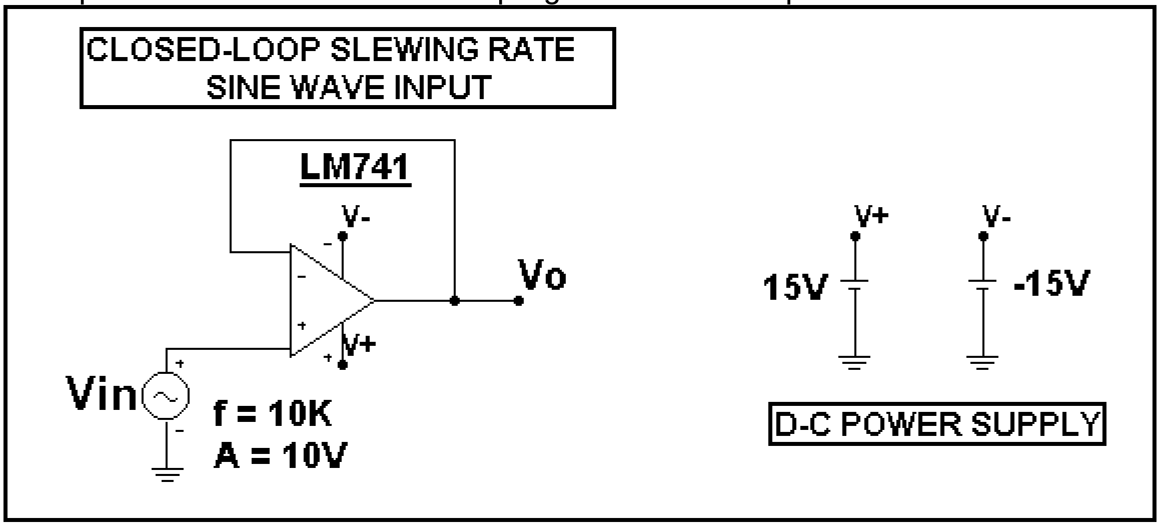
Run the Analysis.



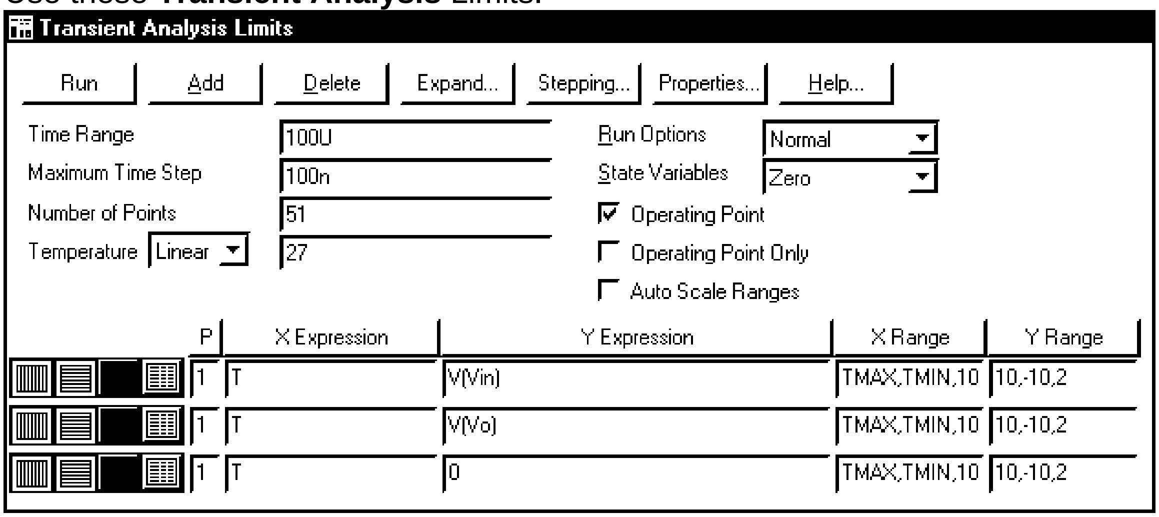
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

Exp 4.10 Closed-Loop Slewing Rate – Sine-Wave Input

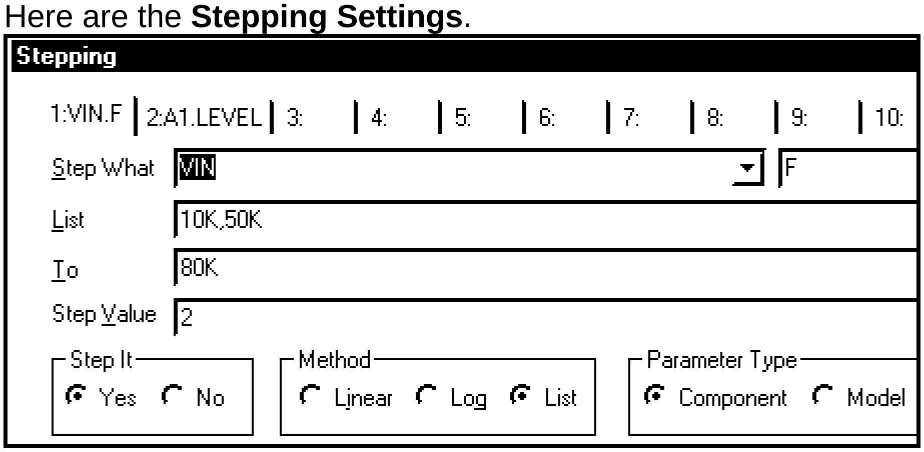
Set up this circuit in the simulation program and on the proto-board.



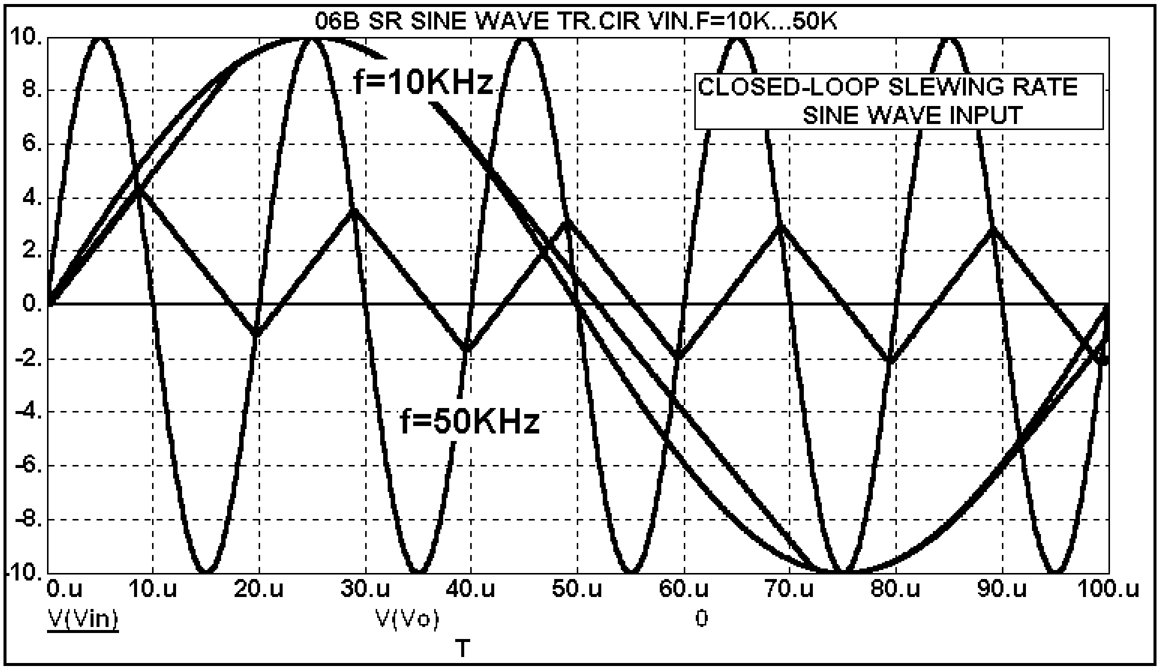
Use these **Transient Analysis** Limits.



Here are the **Stepping Settings**.



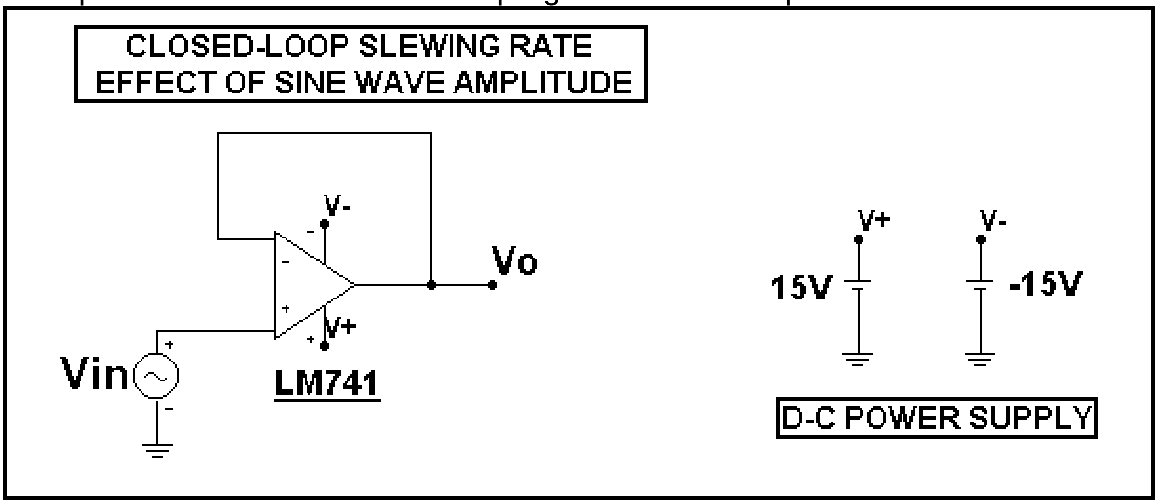
Run the Analysis.



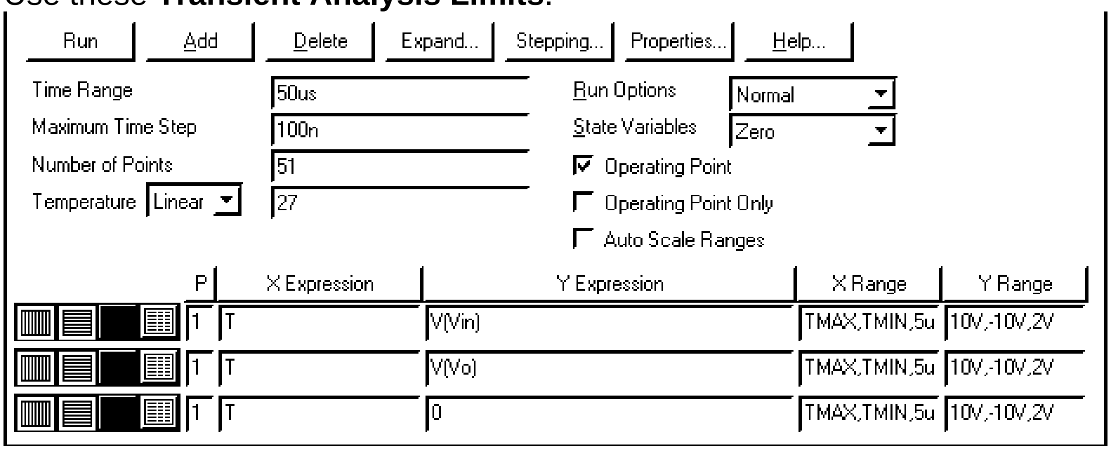
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

Exp 4.11 Closed-Loop Slewing Rate – Effect of Sine Wave Amplitude

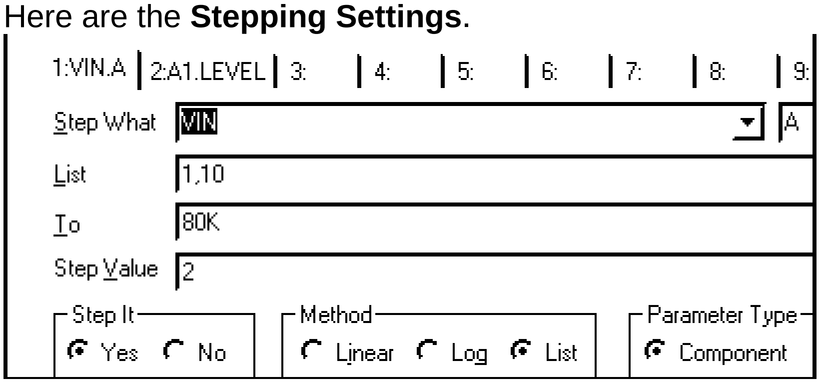
Set up this circuit in the simulation program and on the proto-board.



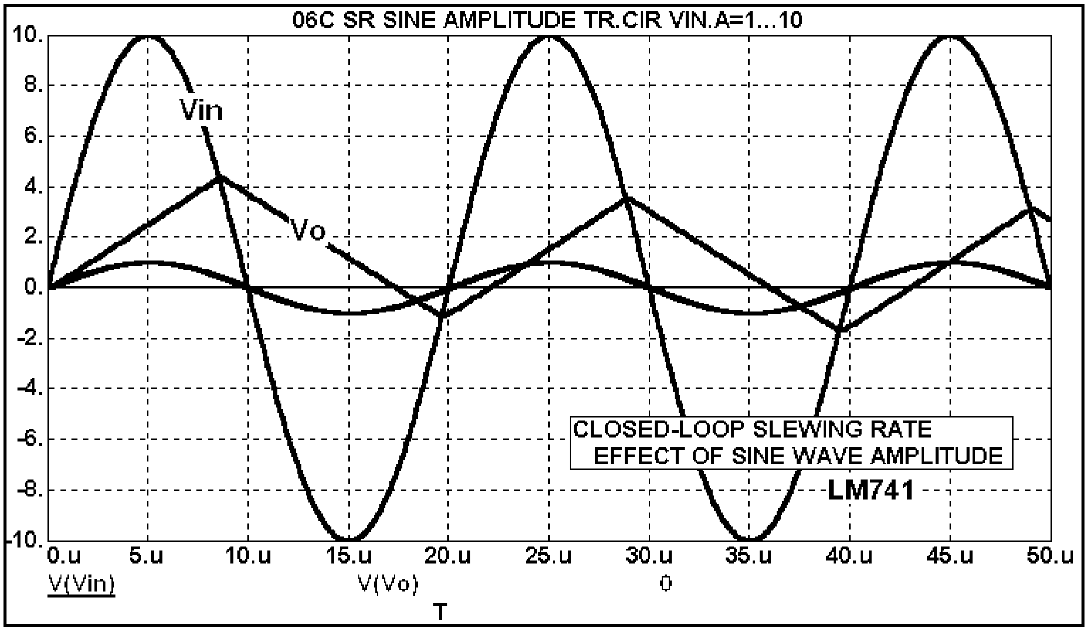
Use these **Transient Analysis Limits**.



Here are the **Stepping Settings**.



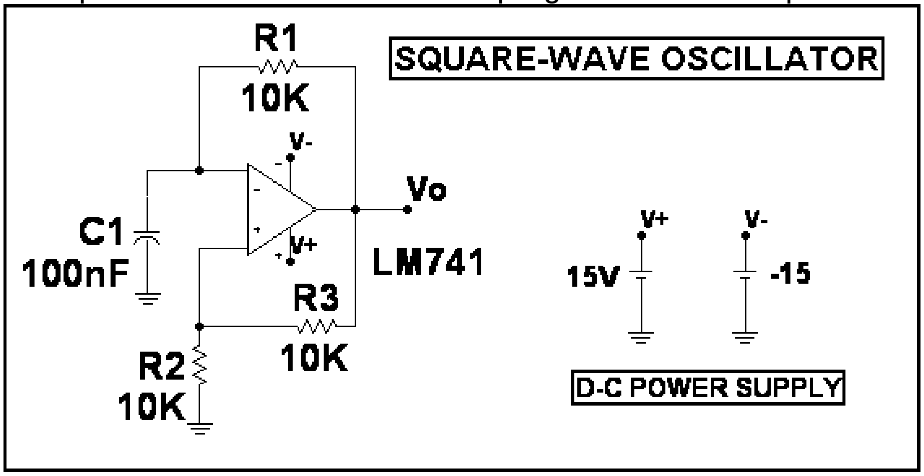
Run the Analysis.



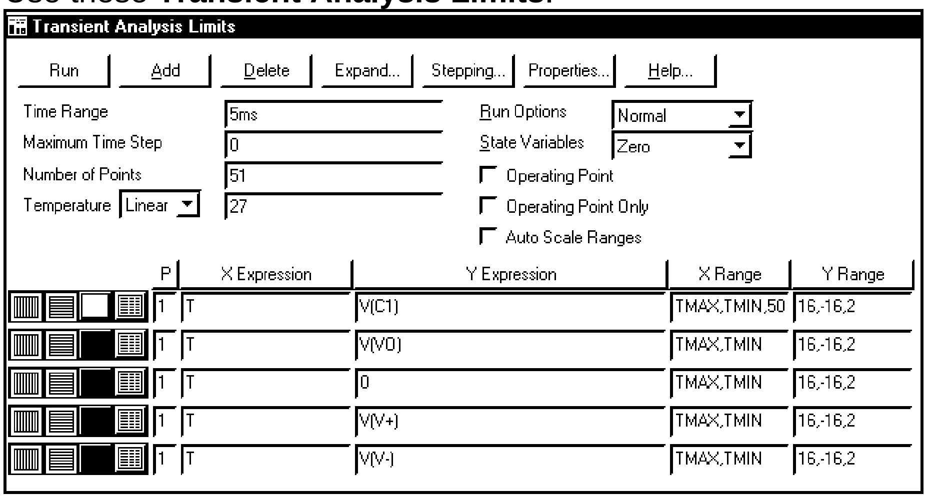
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

Exp 4.12 Square-Wave Oscillator 440 Hz

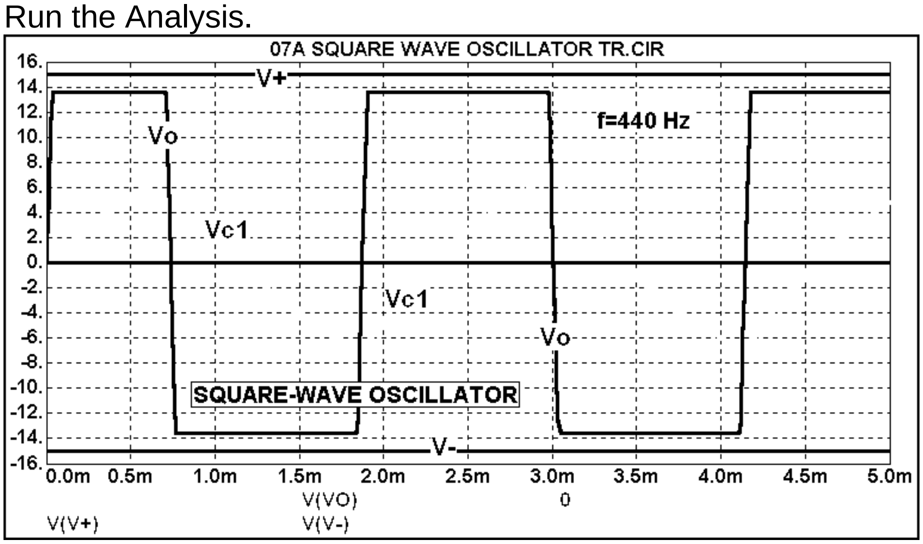
Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis Limits**.



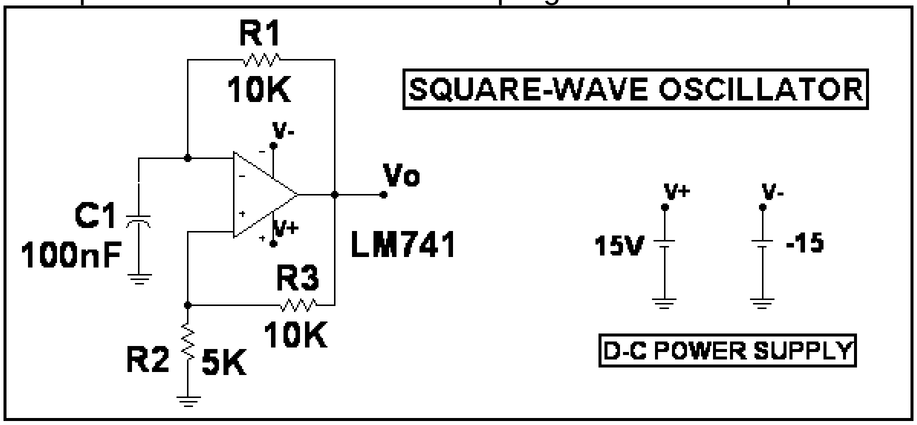
Run the Analysis.



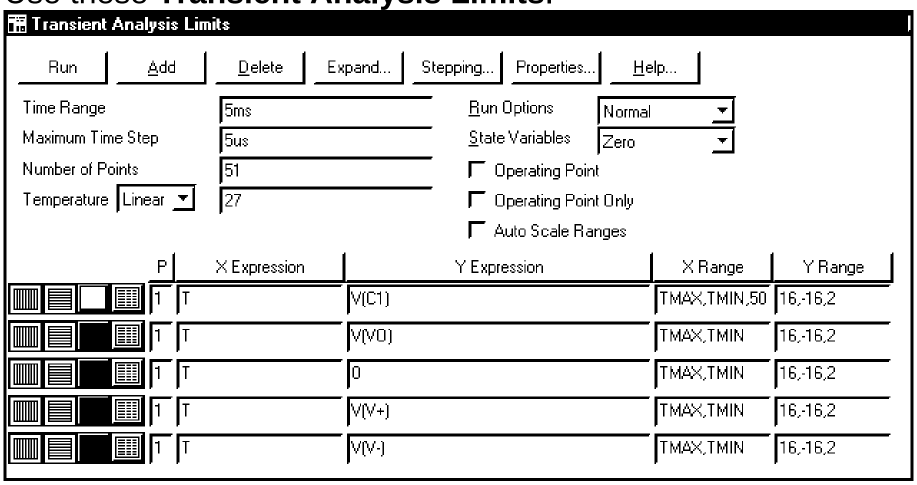
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. Compare the frequency with the expected value as given by the equation **$f = 1 / [2 \cdot R_1 \cdot C_1 \cdot \ln (3)]$**

Exp 4.13 Square-Wave Oscillator 680 Hz

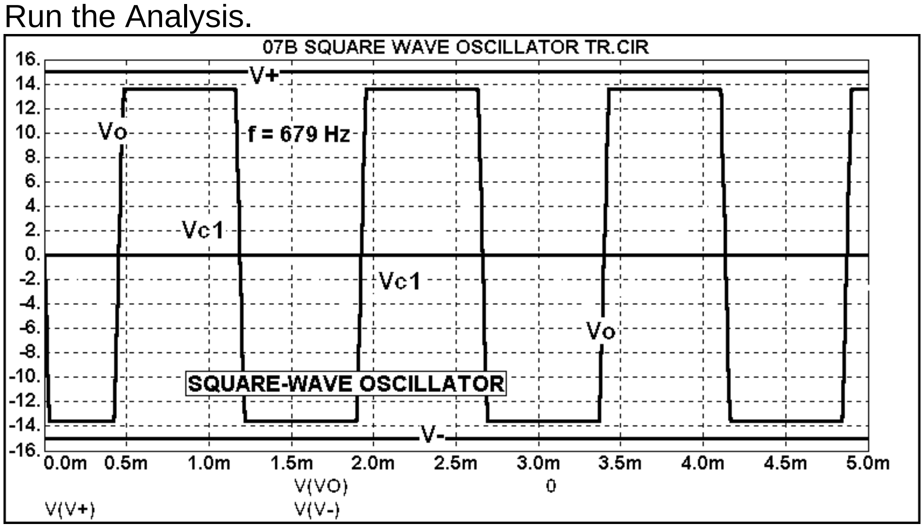
Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis Limits**.



Run the Analysis.

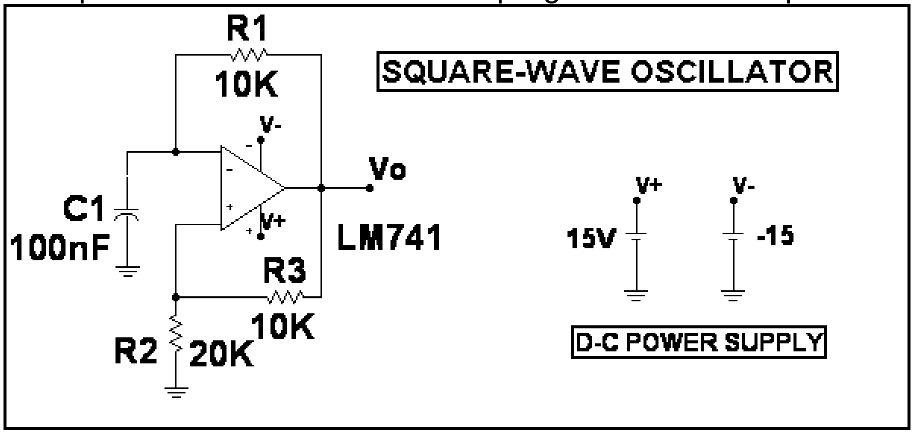


Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.
Compare the frequency with the expected value as given by the equation

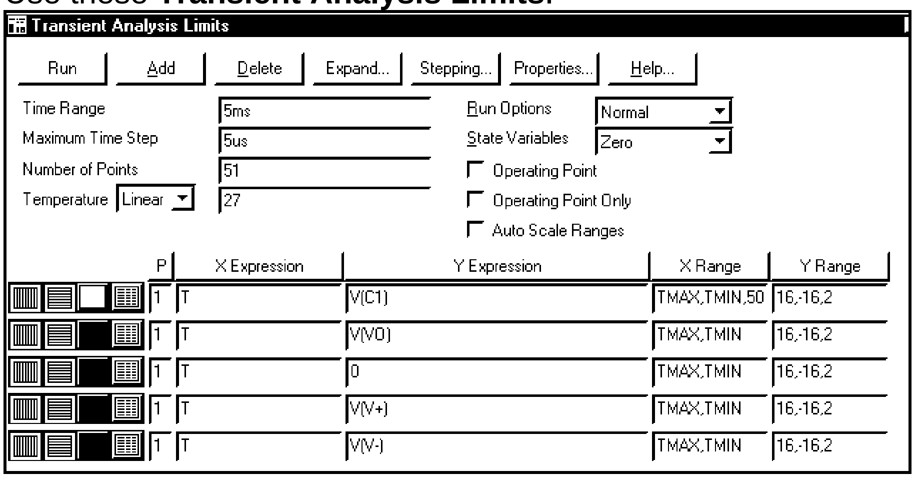
$$f = 1 / [\, 2 \cdot R_1 \cdot C_1 \cdot \ln (1 + 2 \cdot R_2 / R_3) \,]$$

Exp 4.14 Square-Wave Oscillator 300 Hz

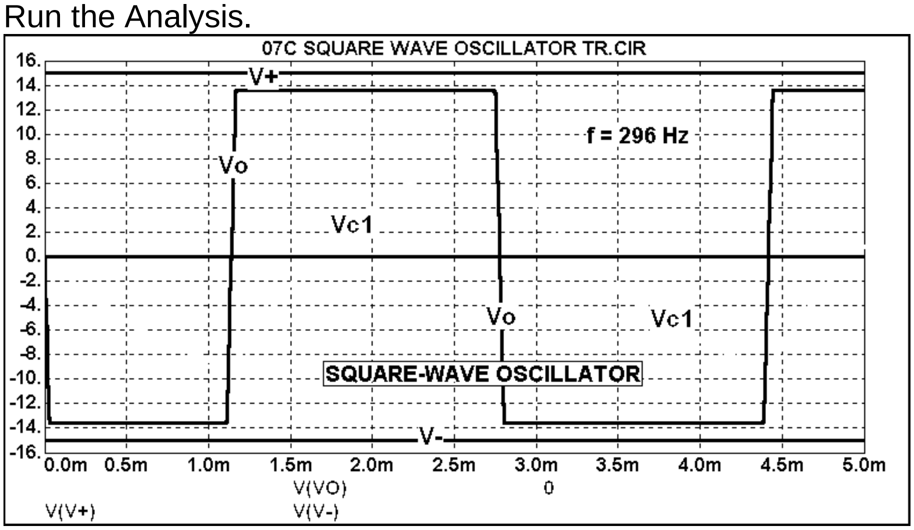
Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis Limits**.



Run the Analysis.

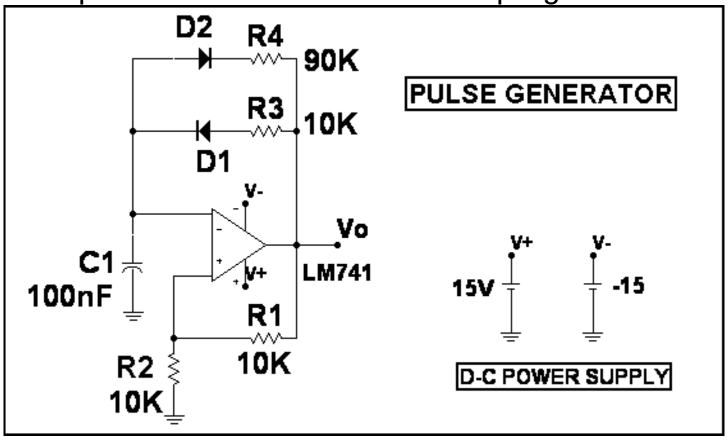


Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.
Compare the frequency with the expected value as given by the equation

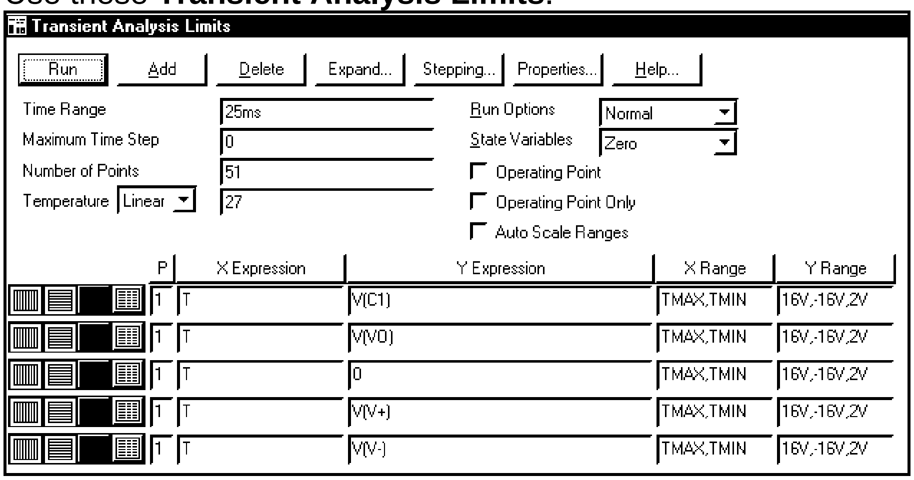
$$f = 1 / [\, 2 \cdot R_1 \cdot C_1 \cdot \ln (1 + 2 \cdot R_2 / R_3) \,]$$

Exp 4.15 Pulse Generator

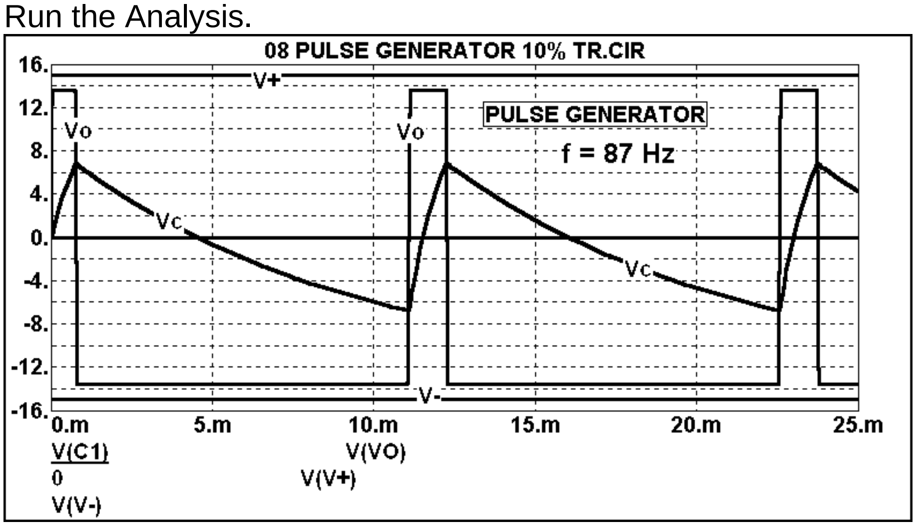
Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis Limits**.



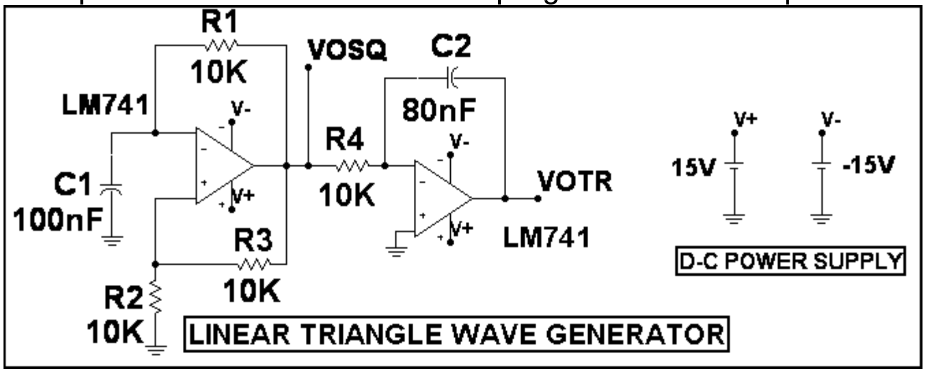
Run the Analysis.



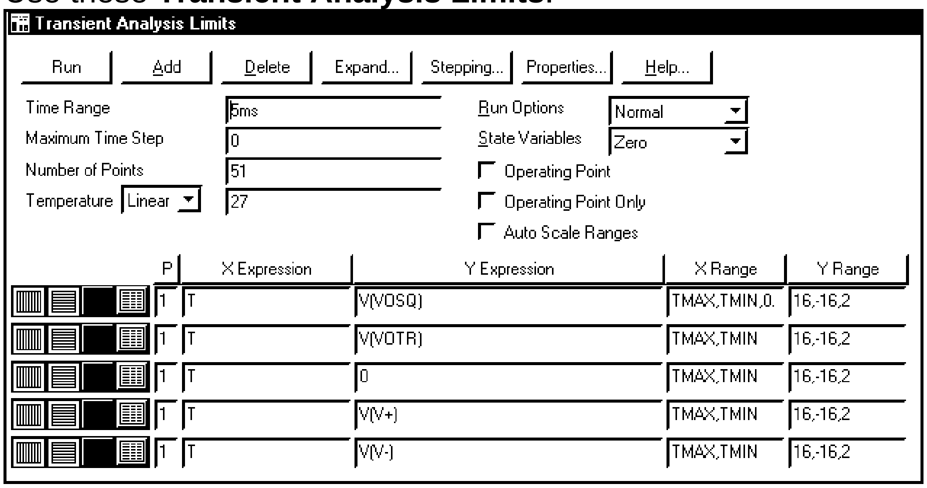
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. Compare the duty cycle with the expected value. Compare the frequency with the expected value. Hint: modify the equation given in Experiment 4.11

Exp 4.16 Linear Triangular Wave Generator

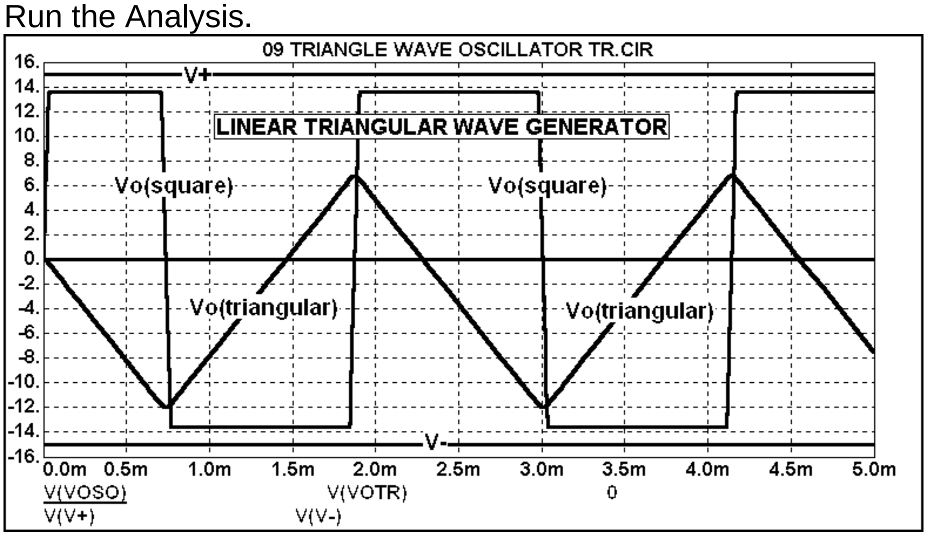
Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis Limits**.



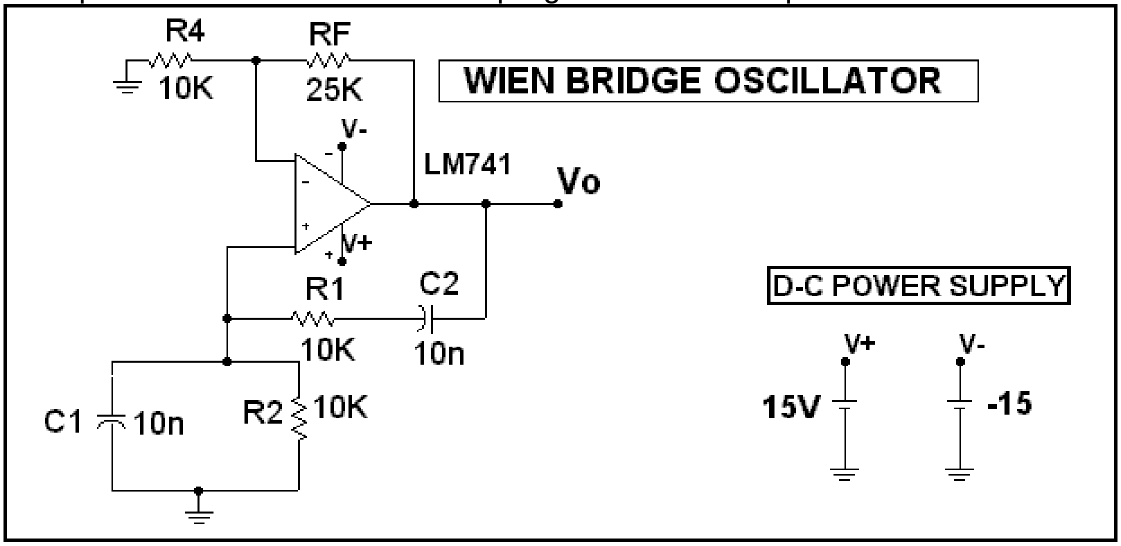
Run the Analysis.



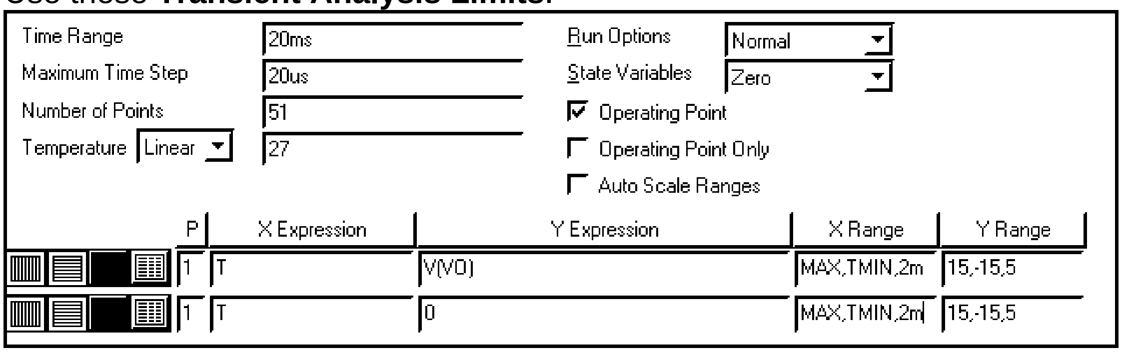
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. Compare the frequency with the expected value. Compare the amplitude of the triangular wave with the expected value.

Exp 4.17 Wien Bridge Oscillator

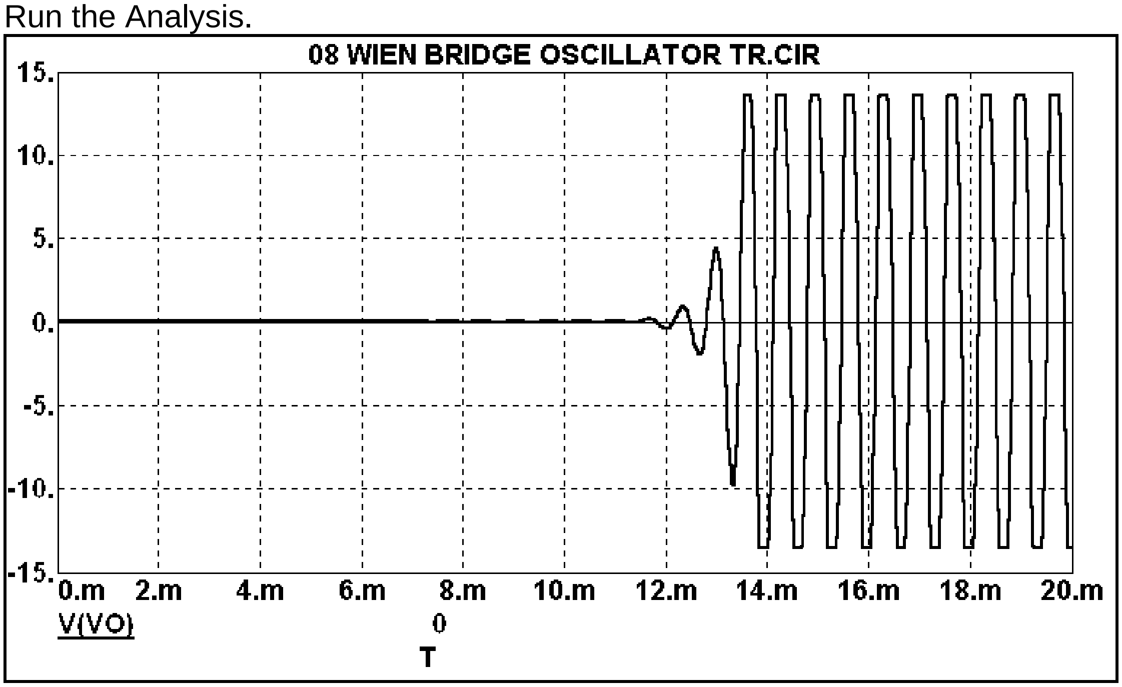
Set up this circuit in the simulation program and on the proto-board.



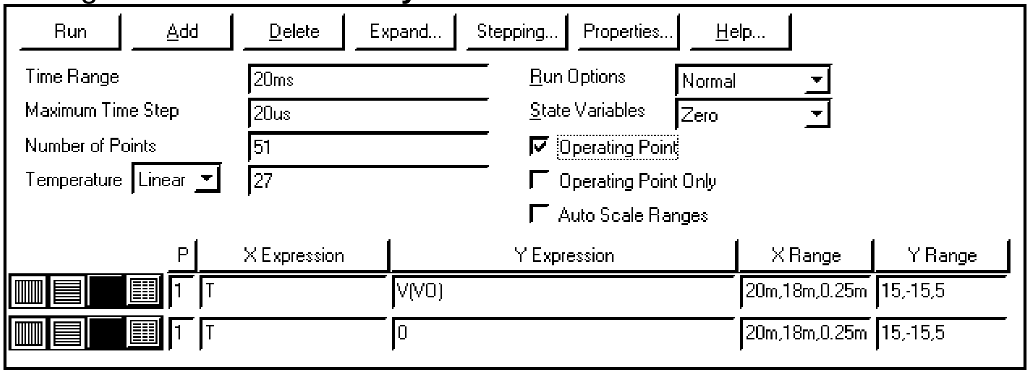
Use these **Transient Analysis Limits**.



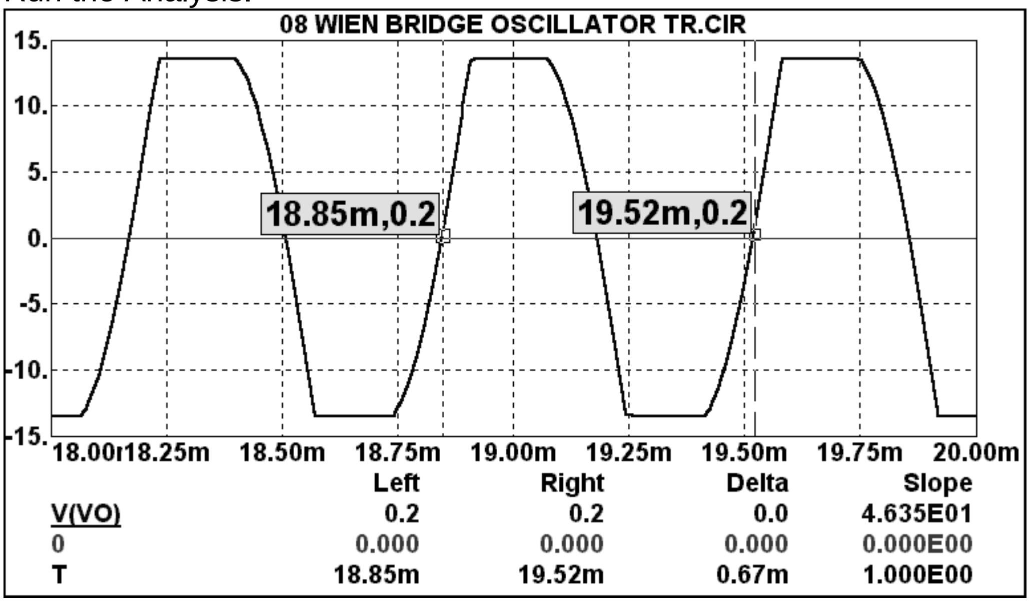
Run the Analysis.



Change the **Transient Analysis Limits** to this.



Run the Analysis.



Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. On the simulation analysis, use the **Cursor Function** (F8) to measure the period of the waveform. From the period calculate the frequency of oscillation. In this example the period T = 0.67 ms, so $f_{OSC} = 1/T = 1.5$ kHz. Compare this with the results shown on the oscilloscope for the actual circuit. Then compare these results with the expected value of

$$\mathbf{f_{OSC} = 1 / [\, 2 \bullet \pi \bullet \sqrt{(R_1 R_2 C_1 C_2)}\,]}$$

If $R_1 = R_2$ and $C_1 = C_2$, as in this circuit, this equation becomes

$$\mathbf{f_{OSC} = 1 / [\, 2 \bullet \pi \bullet R_1 \bullet C_1)\,]}$$

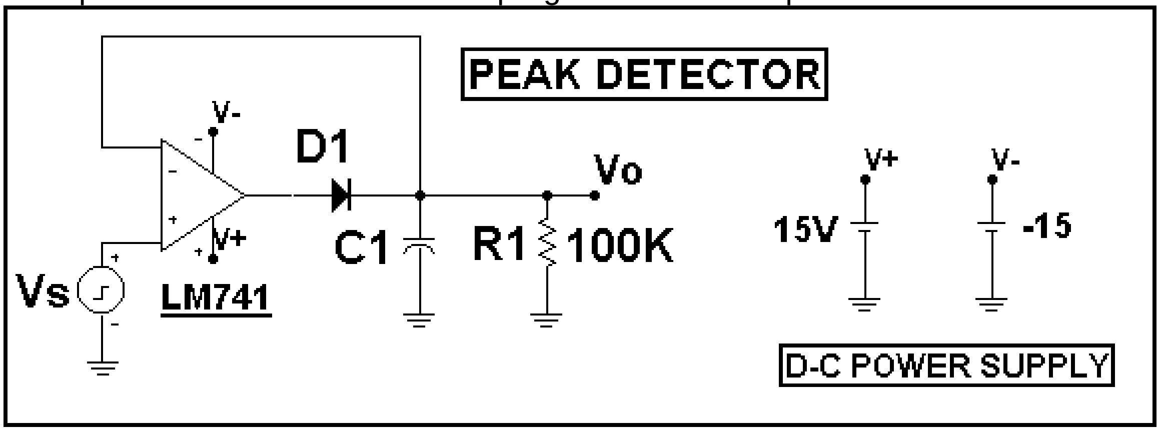
The condition for oscillations to occur is that

$$\mathbf{RF / R4 > (R1/R2) + (C2/C1)}$$

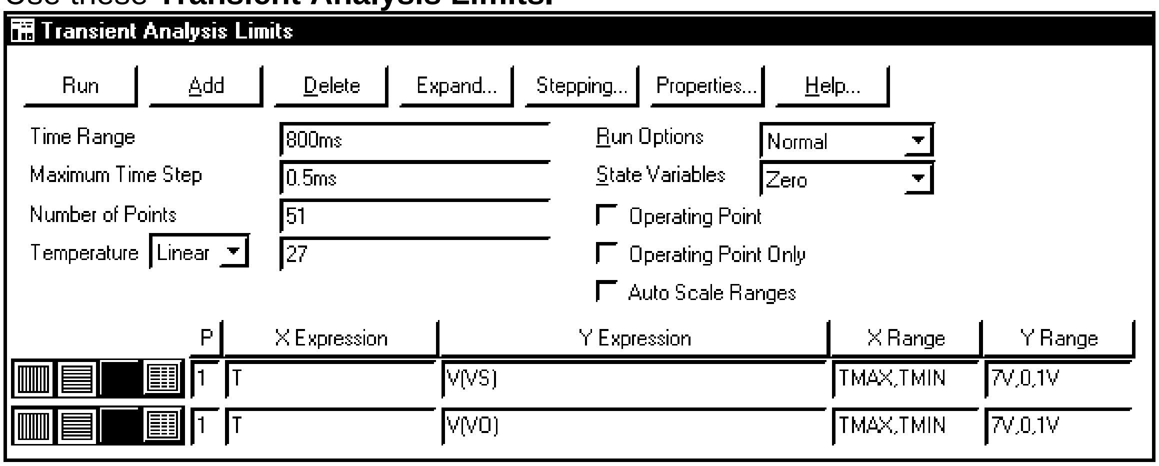
For this circuit this becomes $R_F / R_4 > 2$, so that if $R_4 = 10$ KΩ, then $R_F > 20$ KΩ.
Verify this requirement in the simulation and in the actual circuit by reducing the value of R_F until oscillation ceases.

Exp 4.18 Peak Detector

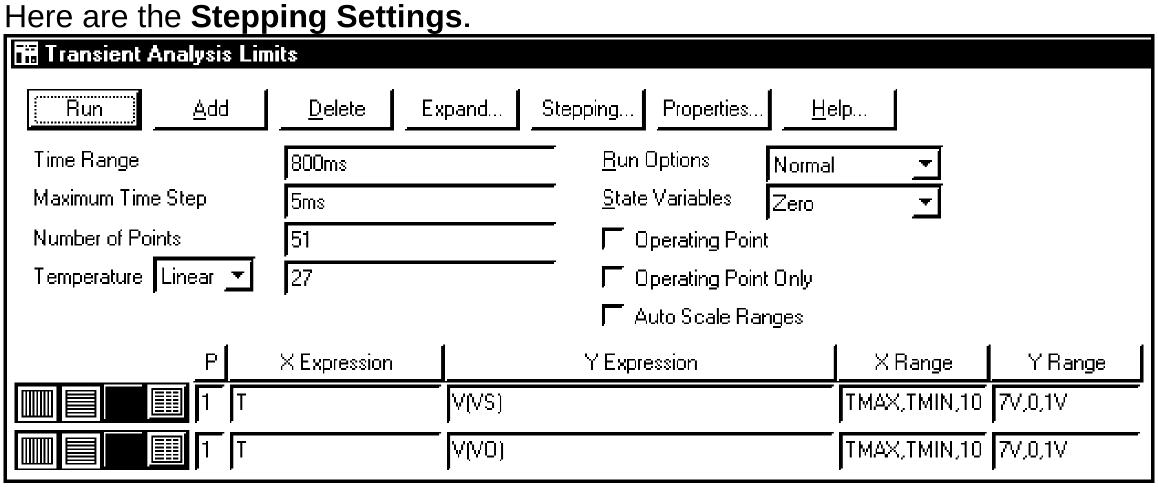
Set up this circuit in the simulation program and on the proto-board.



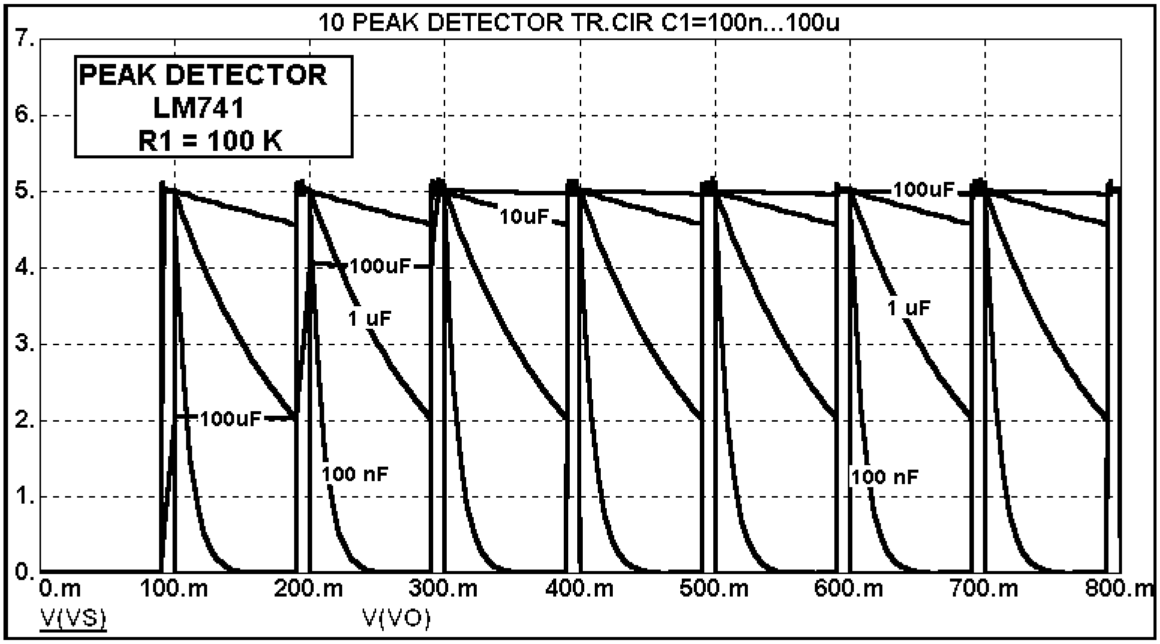
Use these **Transient Analysis Limits.**



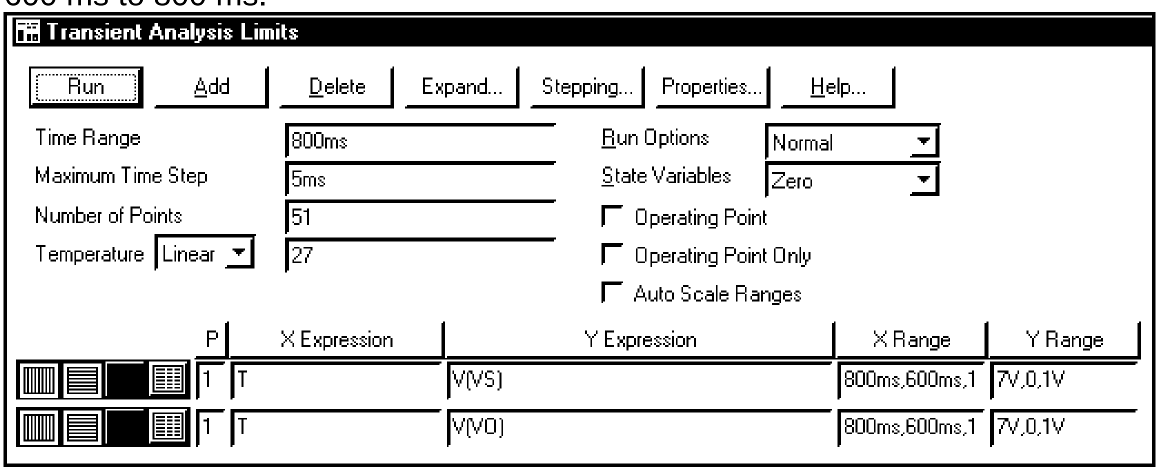
Here are the **Stepping Settings**.



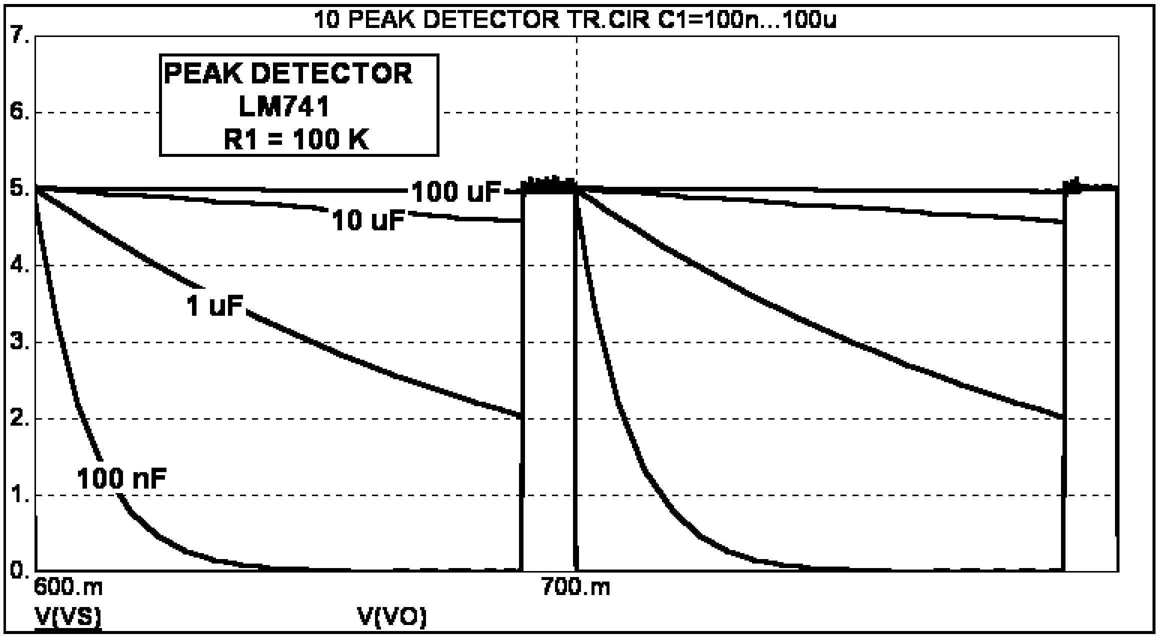
Run the Analysis.



Modify the **Transient Analysis Limits** to show the "steady state" response in the region from 600 ms to 800 ms.



Run the Analysis.



Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

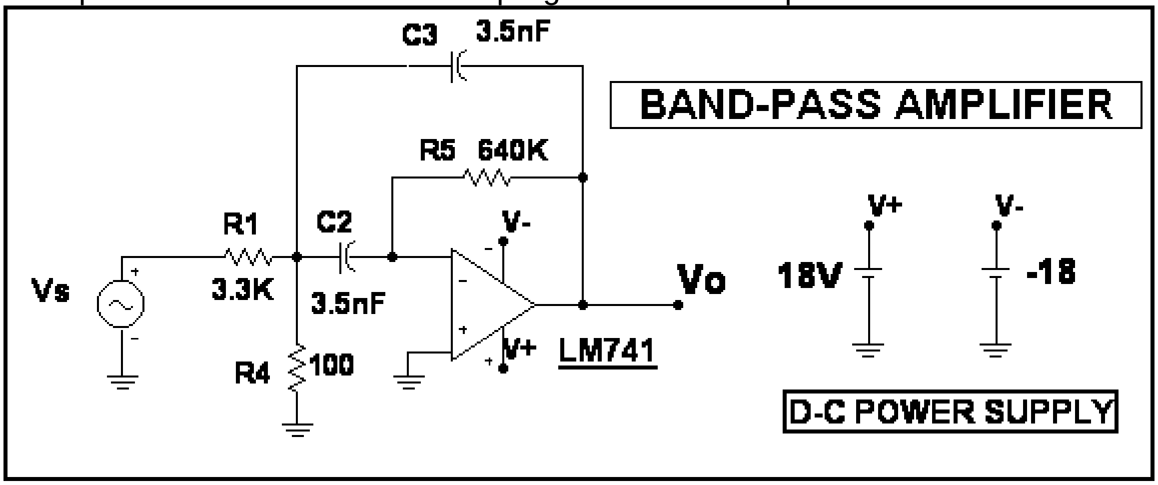
The decay of the output voltage versus time is given by

$$V_O(t) = V_S \cdot \varepsilon^{-t/(R1 \cdot C1)}$$

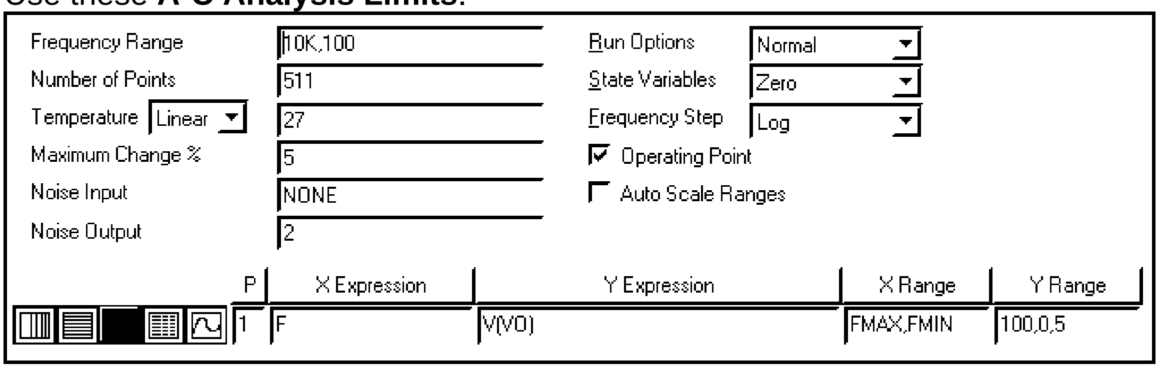
Compare the output voltage level on the oscilloscope at the end of the decay time of 90 ms to the expected value.

Exp 4.19 Band-Pass Amplifier

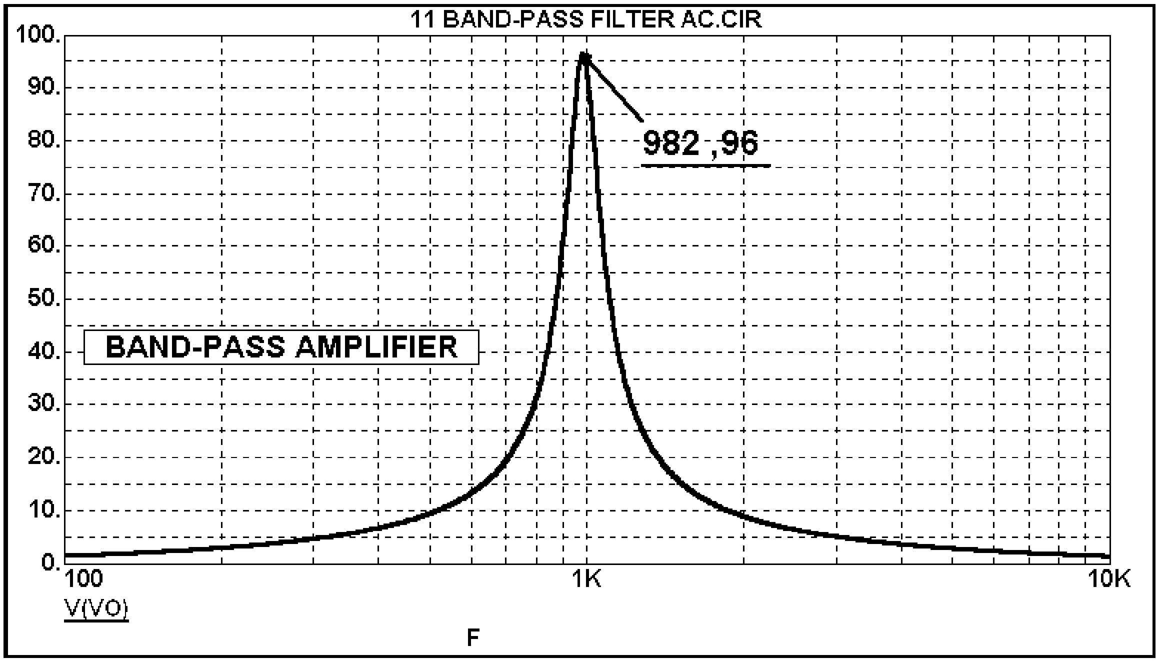
Set up this circuit in the simulation program and on the proto-board.



Use these **A-C Analysis Limits**.



Run the Analysis.



Find the maximum gain and the frequency at which the gain is a maximum for the actual circuit. Compare the results with the simulation.

Compare the results with the expected values. The expected values for the maximum gain and the frequency at which the gain is a maximum are given by

$$f_O = f_{MAX} = \sqrt{\ [G_5(G_1+G_4)/C_2C_3]}\ \ / (2 \bullet \pi)$$

$$A_{V(MAX)} = -\ (R_5/R_1) \bullet C_2/(C_1 + C_2)$$

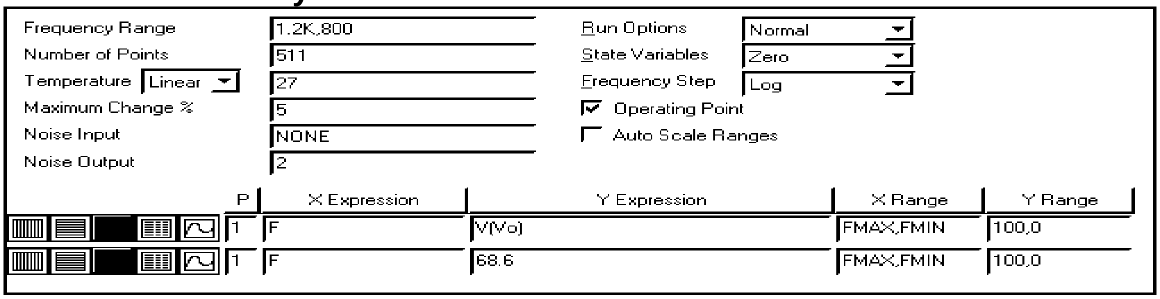
If $C_2 = C_3 = C$, then these equations become

$$f_O = f_{MAX} = \sqrt{[G_5(G_1+G_4)]}\ \ / (2 \bullet \pi \bullet C)$$

$$A_{V(MAX)} = -\ R_5/\ (2 \bullet R_1)$$

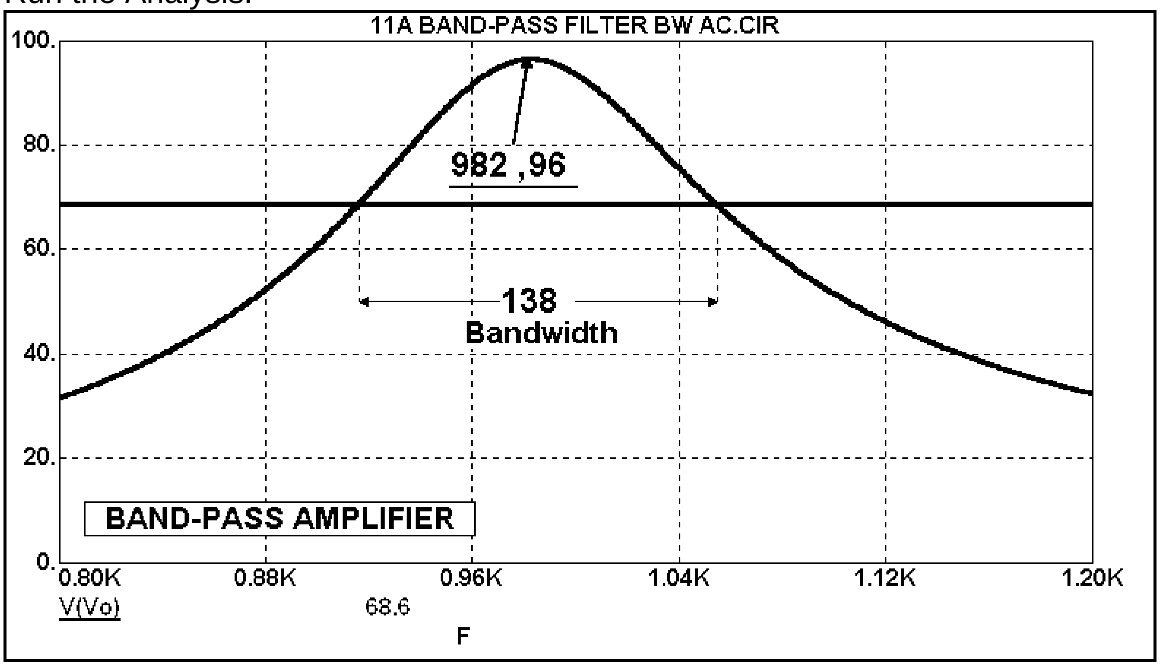
Exp 4.20 Bandwidth of the Band-Pass Amplifier

Use these **A-C Analysis Limits**.



The line at the value of 68.6 is at the maximum value of the gain divided by √2.

Run the Analysis.



Test the circuit and find the two frequencies at which the gain is below the maximum value by a factor of √2, and from that determine the bandwidth. Compare the bandwidth with the simulation.

Compare the results with the expected values. The expected values for the bandwidth is given by

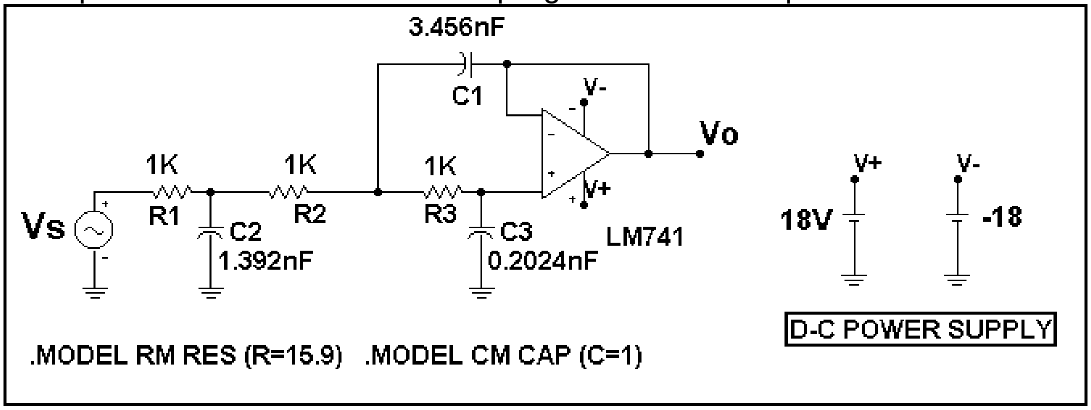
$$[G_5(C_2+C_3)/(2 \cdot \pi \cdot C_2 \cdot C_3)$$

If $C_2 = C_3 = C$, then these this equation becomes

$$1/(\pi \cdot R_5 \cdot C)$$

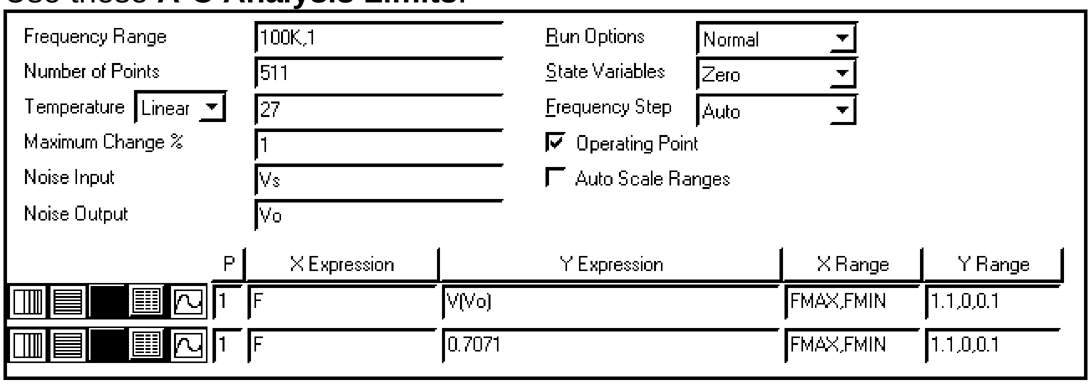
Exp 4.21 Three-Pole Butterworth Low-Pass Filter

Set up this circuit in the simulation program and on the proto-board.

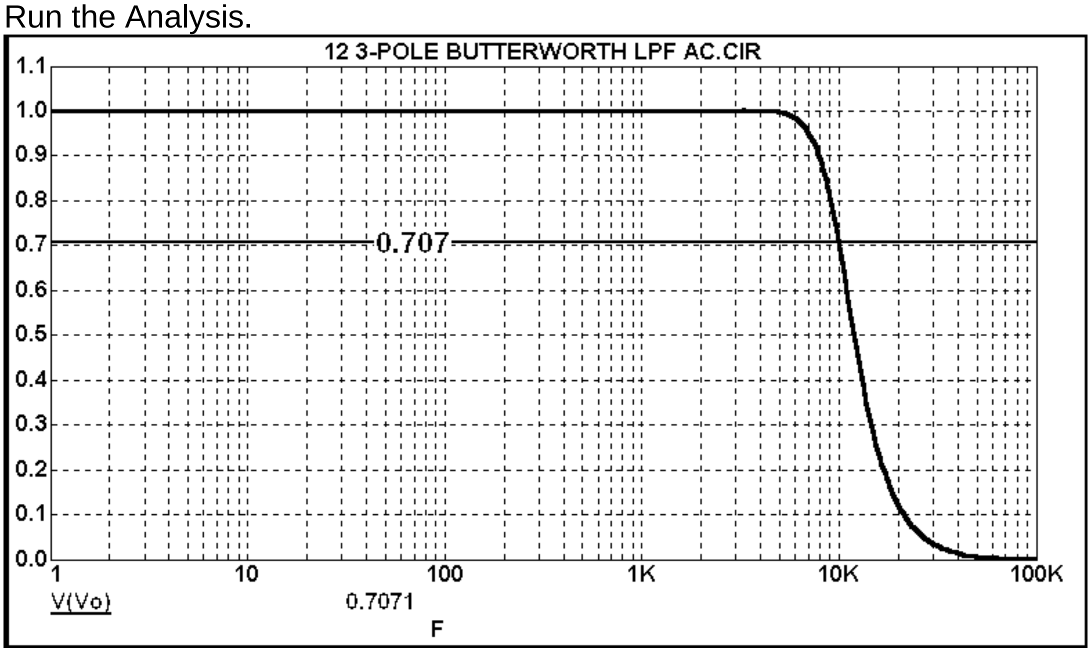


In this case the resistor values are all 1KΩ • R = 15.9 kΩ.

Use these **A-C Analysis Limits**.

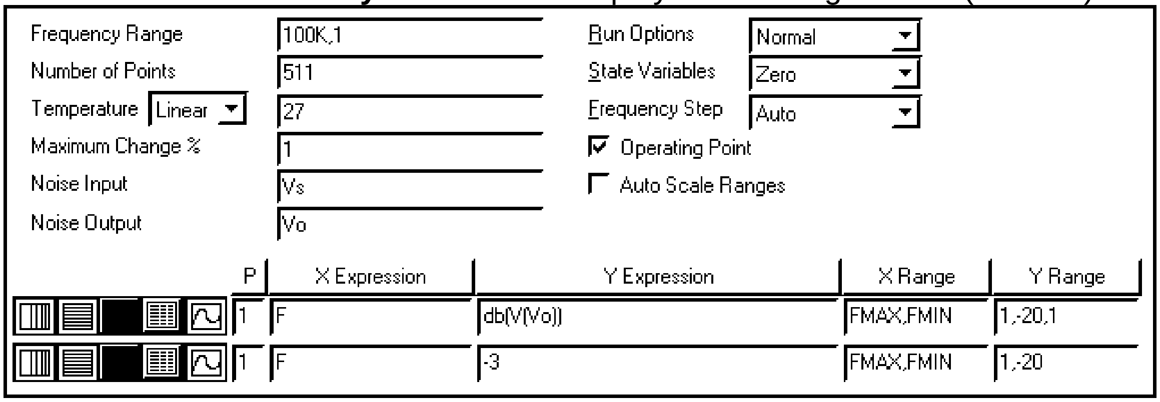


Run the Analysis.

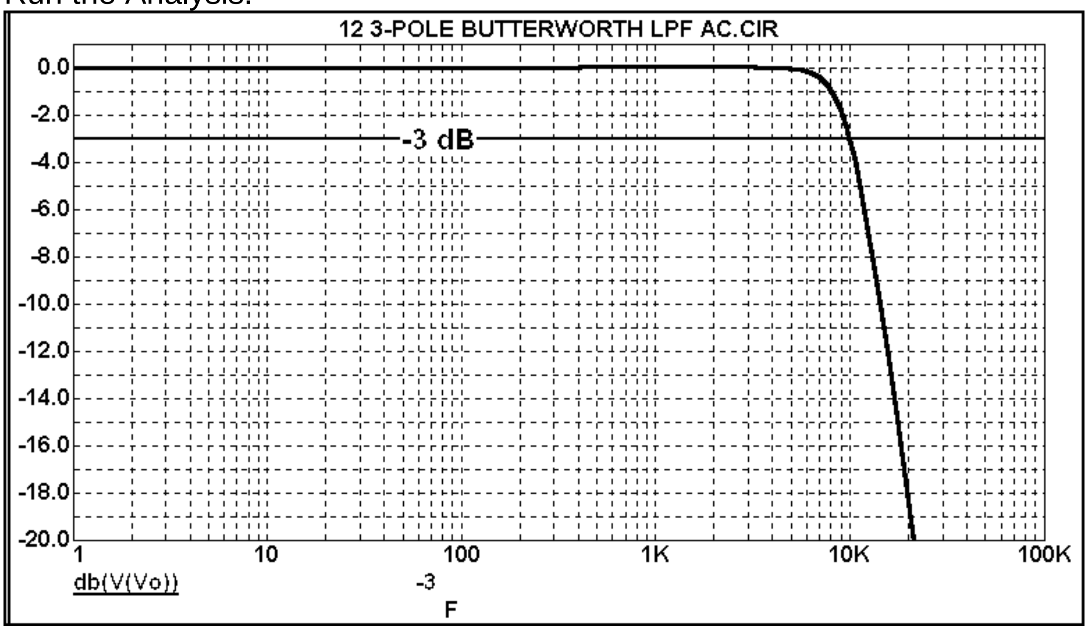


This is with the output voltage, V_O on a linear scale.

Now use these **A-C Analysis Limits** to display V_O on a logarithmic (decibel) scale.

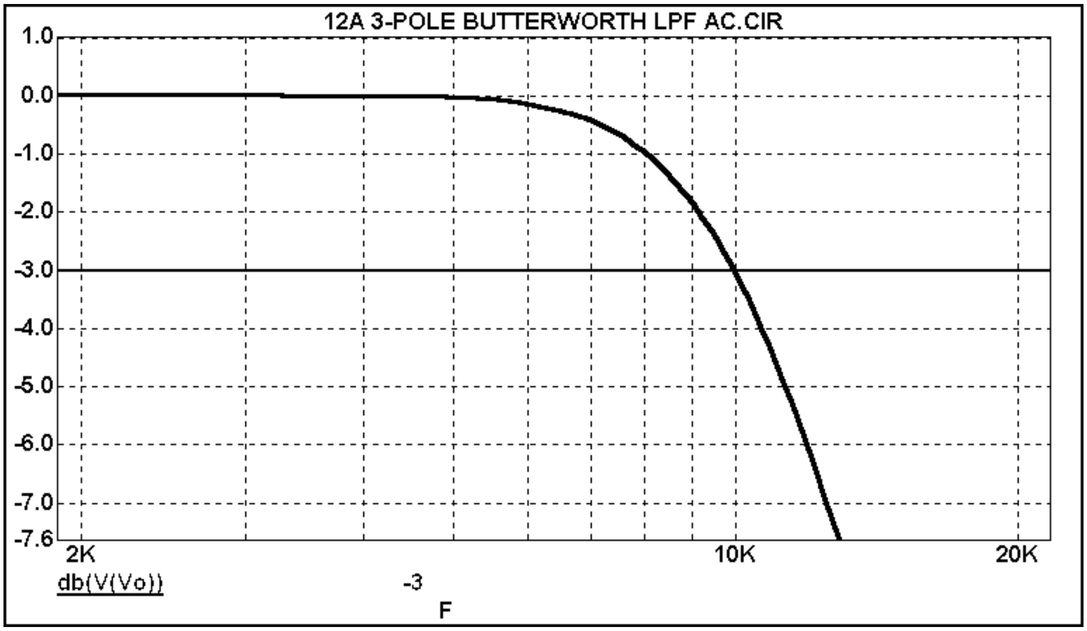


Run the Analysis.



The decibel values are given by $V_O(dB) = 20 \bullet Log_{10}(V_O/V_S)$. When V_O is down by a factor of $1/\sqrt{2}$, the decibel value of the gain is - 3 dB.

Here is a close-up view of the region near the – 3 dB frequency (also known as the half-power frequency).

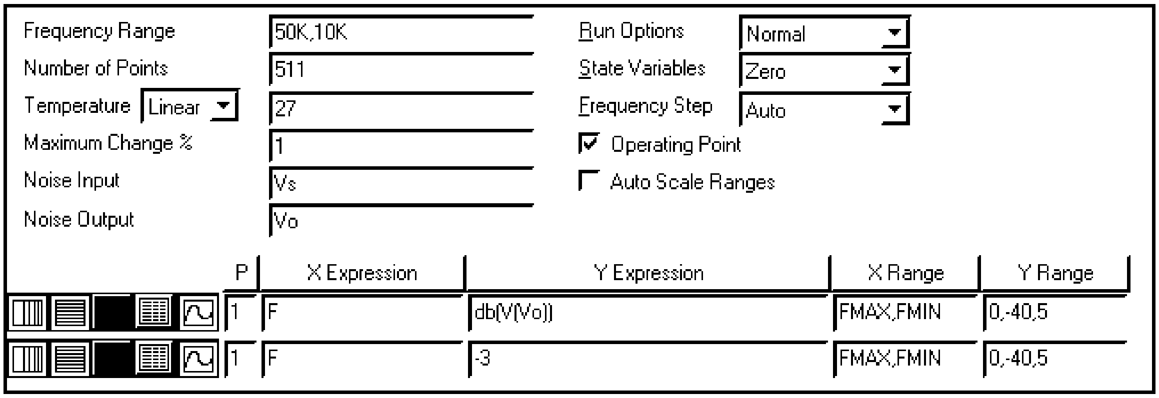


Find the –3 dB frequency on the actual circuit and compare it to the simulation value, and to the value obtained from the equation

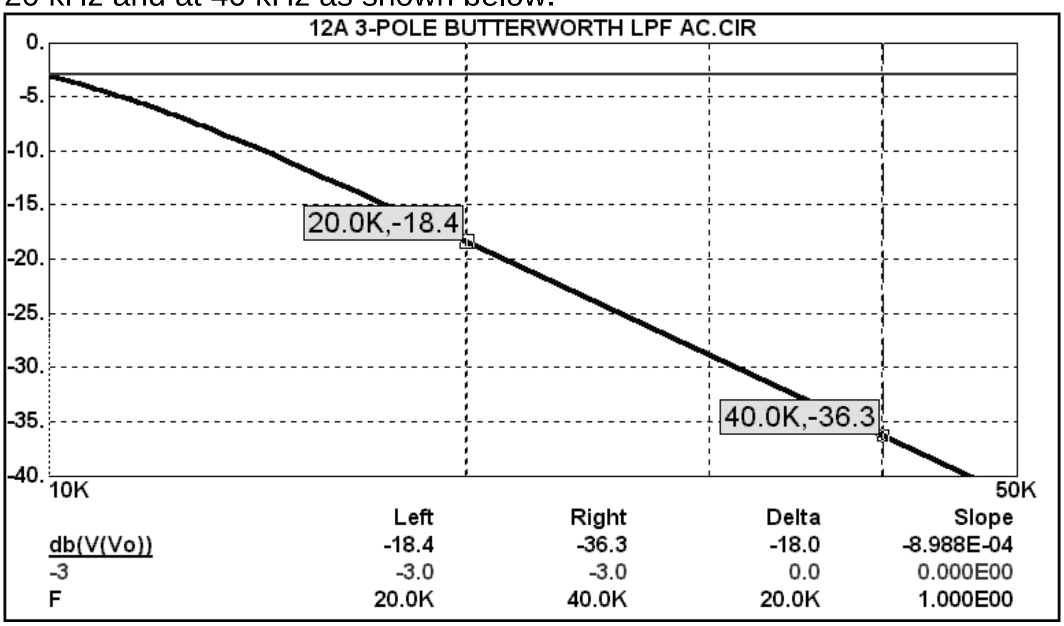
$$f\,(3\text{ dB}) = 1 / (2 \cdot \pi \cdot R \cdot C)$$

Exp 4.22 Slope in the Stop Band

Find the slope of the roll-off in the stop band and compare it to the expected value for a 3-pole filter of 3 • 20 dB/decade = -60 dB/decade which also corresponds to 3 • 6 dB/octave = -18 dB/ octave, where an octave is a 2:1 frequency ratio. Do this on the simulation using these analysis limits



to get the graph as shown below. Use the cursor function (F8) to measure the transfer ratio at 20 kHz and at 40 kHz as shown below.



Make corresponding measurements on the actual at 20 kHz and 40 kHz, to find the slope of the roll-off and compare results.

Experiment 5.1 Chaos in nonlinear systems

Background:

The theory of nonlinear dynamical systems and Chaos is an intriguing area of mathematics that has received considerable attention in the recent past largely due to our ability to now analyze and describe chaotic behavior that for instance can result from the simplest of iterative maps based on basic algebraic equations. Evidently, nature's complex patterns of behavior can sometimes be described by simple equations running in chaotic mode and possibly leading to observed Fractal patterns. The theory of Chaos has found applications in a wide range of areas from multi-level pseudo-random sequences that may be used in communications and Radar applications to reconfigurable logic gates. It turns out that simple thresholding of inputs and outputs of some basic Chaotic systems can lead to familiar logic behavior on binary inputs leading to familiar logic gates. We note that the fundamental system remains Chaotic, it is only when thresholding is applied that the logical pattern of behavior emerges.

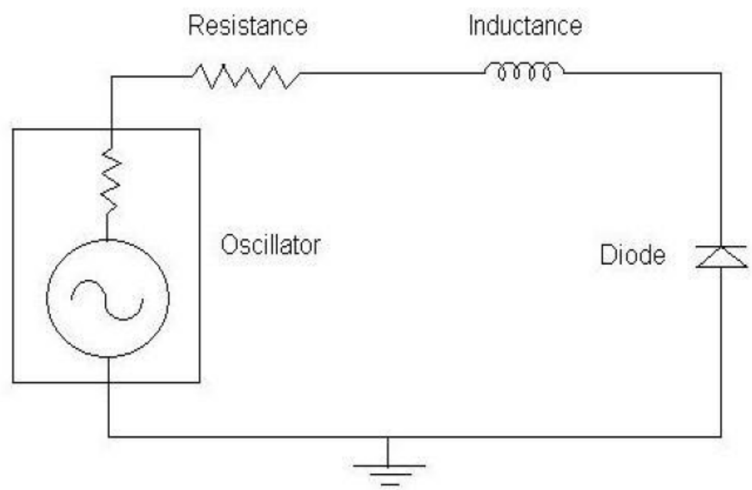
Some of the Navy's highest priorities, such as improved communications, increased bandwidth, improved sensors, and more effective countermeasures for dealing with improvised explosive devices, are currently being addressed by nonlinear dynamics technology.

One application example in NAVY is a nonlinear sensor for magnetic detection. For this application, a variant of stochastic resonance is applied in the design of a nonlinear fluxgate magnetometer to detect the metal in objects that range in size from guns and rifles to the hull of a submarine.

Yet another application of the theory is in design of nonlinear filters to deal with interference and multipath in submarine communication systems. A submarine's ultra high frequency satellite communication (UHF SATCOM) antenna is constrained by the size of the submarine mast and must operate a few inches above the ocean surface where sea states can create dynamic multipath reflections. In addition, UHF SATCOM channels are frequently unusable due to in-band, co-site narrowband interference. For this application, a nonlinear adaptive filter is designed to remove both the interference and multipath signals, thereby increasing the number of usable UHF SATCOM channels while maximizing the data rate.

The Experiment:

The basic ideas of bifurcation and chaos can easily be demonstrated in a simple laboratory experiment with a diode providing the basic nonlinear map. A simple circuit consisting of an inductor, resistor, and diode exhibits chaotic behavior even if the input driving voltage is periodic:



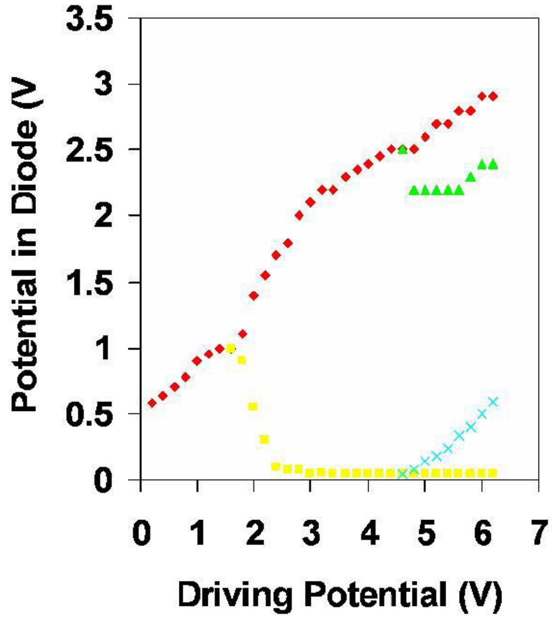
The circuit parameter values for this experiment are as follows:

- Resistance: 200 Ω, 5% tolerance (if not 5% it is O.K.)
- Inductance: 25 mH
- Diode: any silicon diode would do (e.g., 1N..)

The diode exhibits two capacitive effects, one due to charge in depletion layer denoted Junction capacitance C_j, one due to time dependence of the injected charge across the depletion layer under forward bias denoted diffusion capacitance of C_d. These are usually modeled as being in parallel but C_j dominates under reverse bias while C_d under forward bias.
The diode's capacitance in conjunction with the resistive and inductive circuit elements produce an RLC resonant circuit. When the driving potential is tuned to this resonance frequency the diode potential exhibits bifurcation as a function of the amplitude of the driving potential.

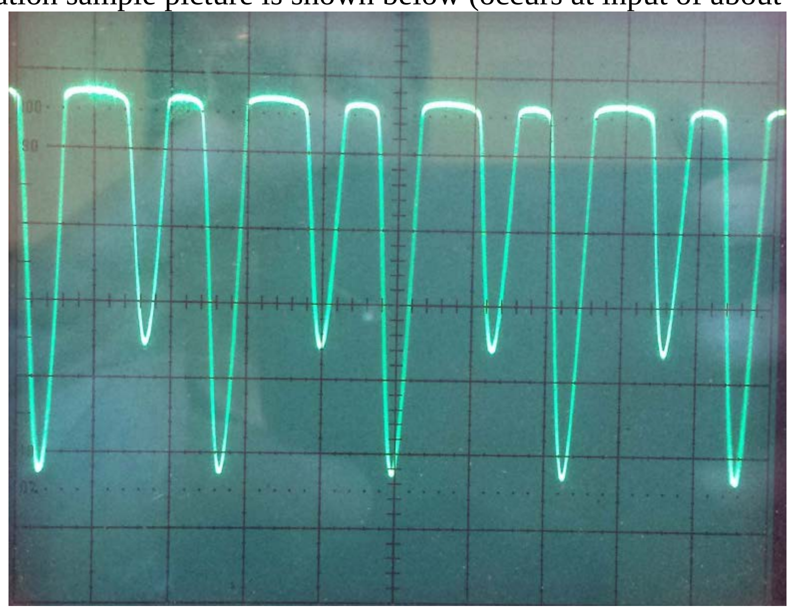
Experimental Procedure:

1. Setup the circuit shown above on a breadboard. The power supply should be set to 1 KHz sinusoidal AC, initially at 100 mV Peak to Peak (PP). All measurements in the rest of this experiment will be based on PP voltages. Make sure the AC signal has no DC level (DC offset should be zero);
2. Attach the oscilloscope channel-1 probe across the diode and increase the frequency until the voltage across the diode is maximum. That frequency is the circuit resonance frequency. Record this frequency;
3. Decrease the frequency from resonance until the output is 0.707 of maximum value at resonance, call this frequency f_l. Next increase the frequency above resonance till the output is again 0.707 of the maximum value at resonance, call this frequency f_u. The RLC bandwidth is (f_u-f_l). Finally, set the frequency to the value at resonance and for the rest of the experiment, keep the frequency at this level;
4. Attach the oscilloscope channel-2 probe across the source. You will be measuring the PP voltage at the input and output (across the diode). It is the plot of the PP voltage at output versus input that shows Bifurcation which is characteristic of Chaotic systems. A typical plot after measurements may look like this:

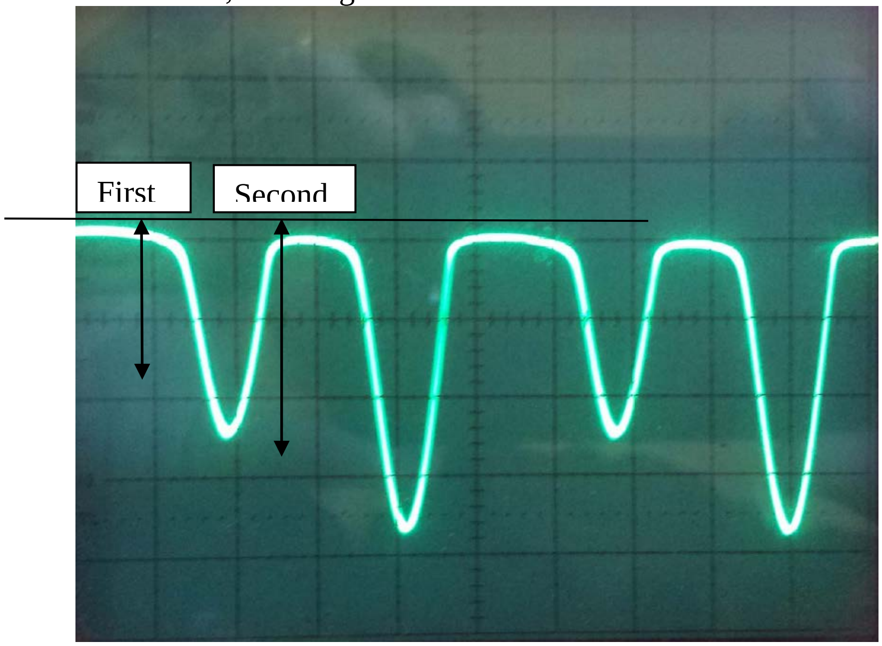


5. Increase the input voltage amplitude from the 100 mV PP level in increments of 200 mV PP and measure the PP output voltage across the diode. Typical pictures that identify various Bifurcation levels are shown below.

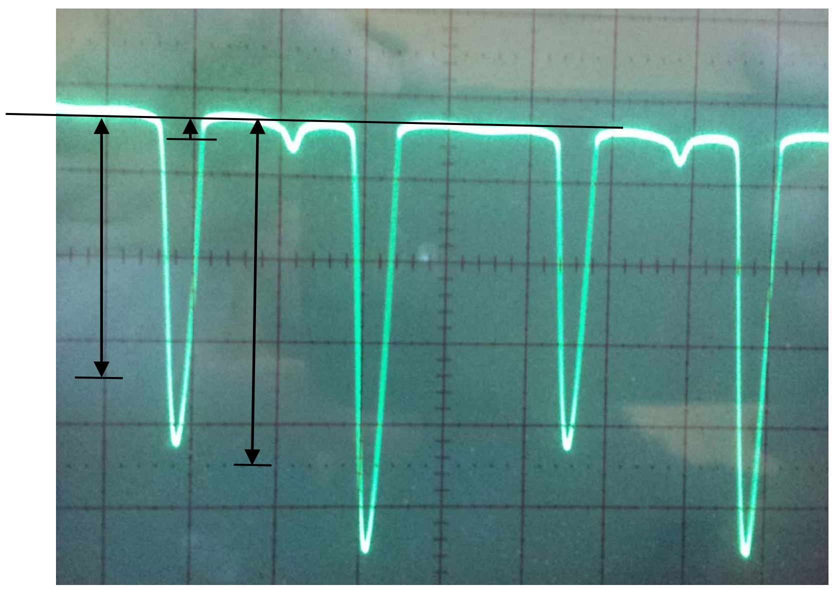
The First level Bifurcation sample picture is shown below (occurs at input of about 1.8 V PP):



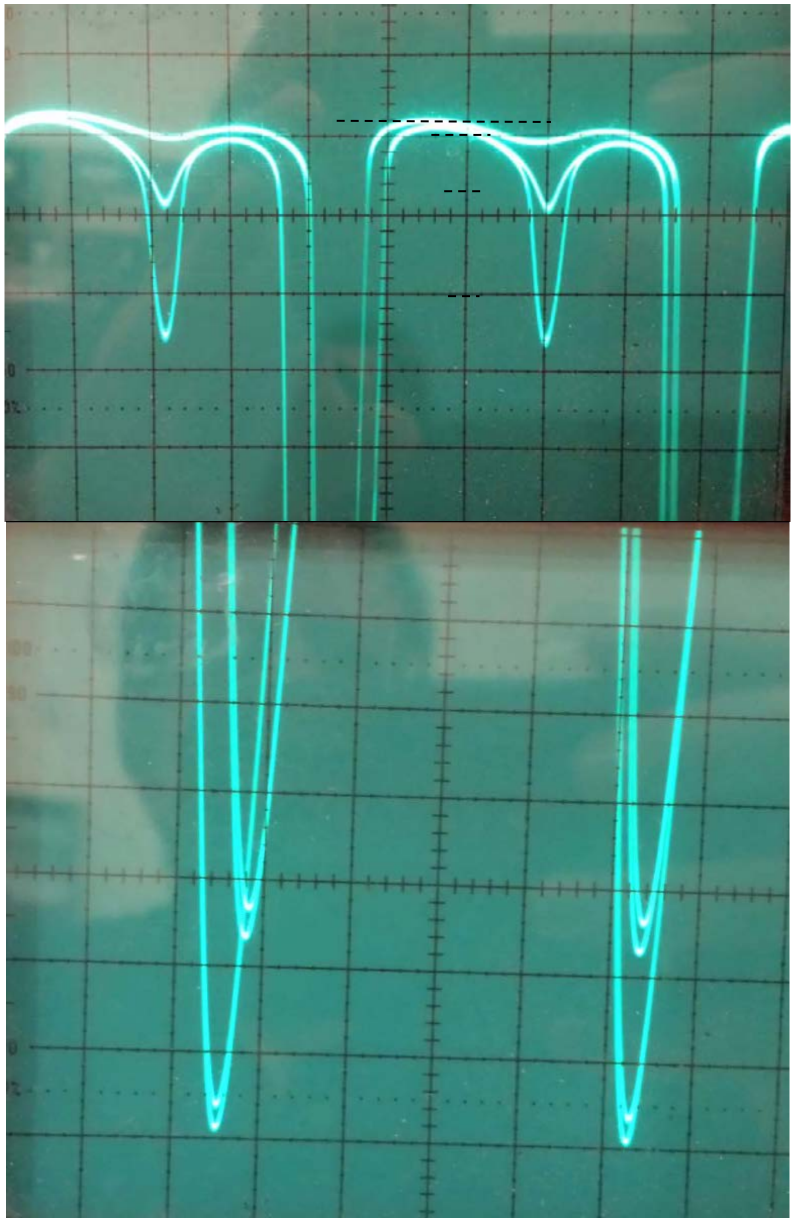
To measure the bifurcation levels, use the guide below:



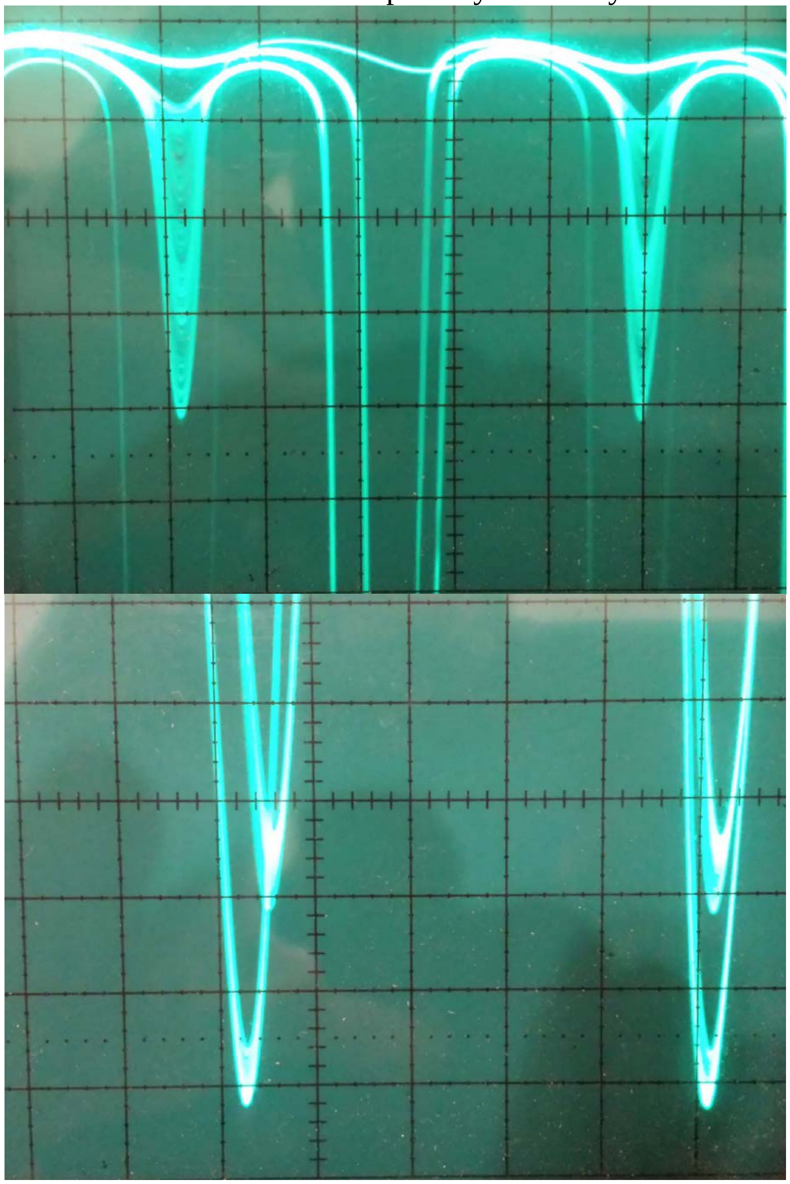
The 2nd level bifurcation picture and the corresponding levels is shown below (occurs at input voltage of about 4.8 V PP):



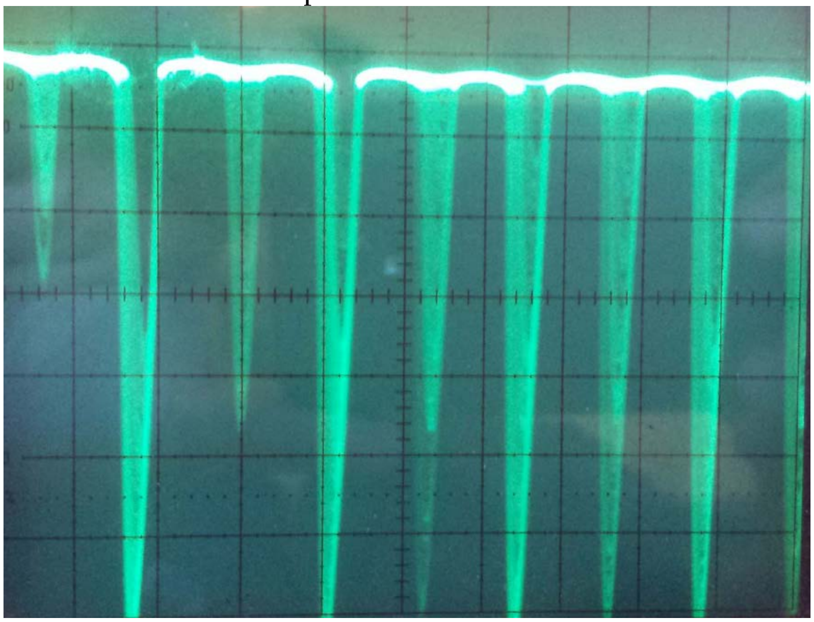
The Third level Bifurcation (occurs at input voltage level of about 5.6 V PP) may not produce a steady single trace picture. Nonetheless, it is possible to clearly identify splitting of the levels to produce 8 potential levels. The lowest level is very near zero. The other low levels show up as dips whose amplitudes define the levels. The top and bottom part of the trace are shown separately for better clarity on the level splitting:



At onset of Chaos (occurs at input voltage level of about 6.2 V PP), blurring of the levels occur as shown below. The top and bottom of the trace are shown separately for clarity:

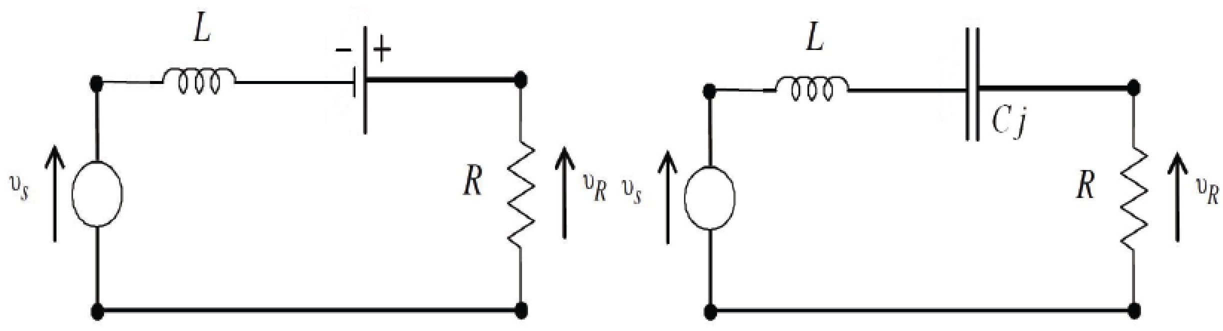


At deep Chaos, the levels can be all over the place:



Analysis:

The circuit equivalent of the diode under Forward Bias (FB) and Reverse Bias (RB) when inserted into the overall circuit diagram leads to the following configurations:



(a) Diode forward bias. (b) Diode reverse bias.

Under FB, the diode behaves like a constant voltage source with voltage level V_f, while under RB it acts like a capacitance of value C_j. Analysis of the circuit under FB with sinusoidal excitation leads to the following; from KVL under FB we get:

$$L\frac{dI}{dt} + RI = V_o \sin(\omega t) + V_f$$

The solution of this differential equation yields:

$$I(t;A) = \frac{V_o}{Z_a}\cos(\omega t - \theta) + \frac{V_f}{R} + Ae^{-Rt/L}$$

Where, V_o is the peak amplitude of the input sinusoid, $\theta = tan^{-1}\left(\frac{\omega L}{R}\right)$, Z_a is the forward bias impedance given by $Z_a = \sqrt{R^2 + \omega^2 L^2}$ and A is a constant to be determined from initial conditions. The KVL under RB condition gives:

$$L\frac{d^2 I}{dt^2} + R\frac{dI}{dt} + \frac{1}{C_j}I = V_o\omega\sin(\omega t)$$

The solution to this equation is given by:

$$I(t;B,\varphi) = \frac{V_o}{Z_b}\cos(\omega t - \theta_b) + Be^{-Rt/2L}\cos(\omega_b t - \varphi)$$

Where, B and φ are constants to be determined from initial conditions and

$$\theta_b = tan^{-1}\left(\frac{L(\omega^2 - \omega_o^2)}{R\omega}\right), \ \ \omega_o^2 = \frac{1}{LC_j}, \ \ {\omega_b}^2 = \omega_o^2 - (\frac{R}{2L})^2$$

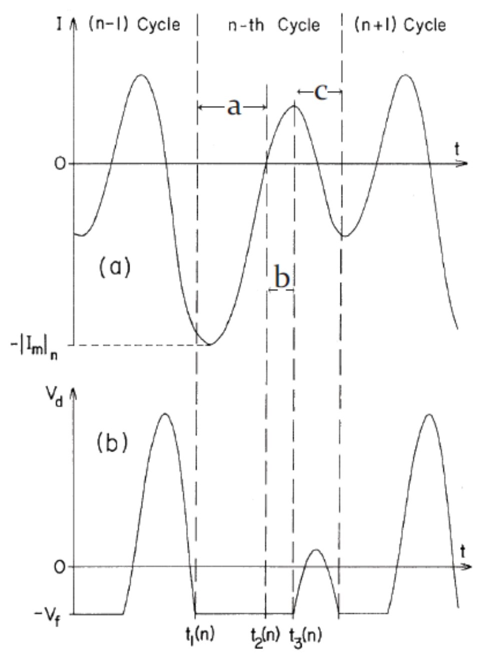
$$Z_b = \sqrt{R^2 + \frac{L^2}{R^2}(\omega^2 - \omega_o^2)}$$

These equations hold valid when the diode drive current is not very large. The nonlinear behavior that leads to Chaos arises due to the fact that the diode cannot switch from FB to RB and vice versa instantaneously and indeed the diode continues to conduct for a period of time τ after the instant of switching. This recovery time is actually dependent on the magnitude of the forward current in the diode $|I_m|$ and is given by:

$$\tau = \tau_m(1 - e^{-|I_m|/I_C})$$

Where, τ_m and I_C are constants that depend on the diode in use.

The figure below illustrates the mechanism of first Bifurcation:



When the circuit is operated at the resonant frequency, some reverse current will flow through the diode in every reverse bias cycle due to the finite recovery time of the diode. If the peak current $|I_m|$ is large in the conducting cycle (interval 'a'), the diode will turn off with a certain delay (interval 'b') due to the finite recovery time and so will allow a current to flow even in the reverse-bias cycle. This reverse bias current, in turn, will prevent the diode from instantly switching on in the forward bias cycle and the diode will turn *on* with a delay (interval 'c'). This will keep the forward peak current smaller than in the previous forward bias cycle, hence leading to two distinct peaks of the forward current. Since it takes *two* cycles of the driving signal in this process t get back to the initial scenario, we identify this as a period-doubling bifurcation. As the input is further increased, another period doubling Bifurcation occurs and now four possible current levels can exist in the diode. This process continues until Chaos where a multitude of levels are possible.

Calculations and Results:

1. From measured resonance and upper and lower frequencies determine the RLC quality factor Q given by $Q = \frac{f_o}{(f_u - f_l)}$, and compare the value to the theory given by $Q = \frac{\omega_o L}{R}$;
2. From the measured resonance frequency, determine the junction capacitance from $\omega_o = \frac{1}{\sqrt{LC_j}}$;
3. Plot the Bifurcation diagram (i.e., PP output versus input voltage) up to the edge of third Bifurcation as shown in the figure above;
4. From two measured recovery times after the first Bifurcation, determine the constants τ_m and I_C for the diode you are using.