

# **LABORATORY MANUAL ELECTRONICS LABORATORY II EE 3709**

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## **USEFUL KEYBOARD SHORTCUTS FOR MICRO-CAP**

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### **ANALYSIS**

ALT + 1 : Transient Analysis

ALT + 2 : A-C Analysis (Frequency Response)

ALT + 3 : D-C Analysis

ALT + 4 : Dynamic D-C Analysis

F3: Schematic Window

F9: Analysis Limits

F2: Run Analysis

F8: Cursor Mode in Analysis Window

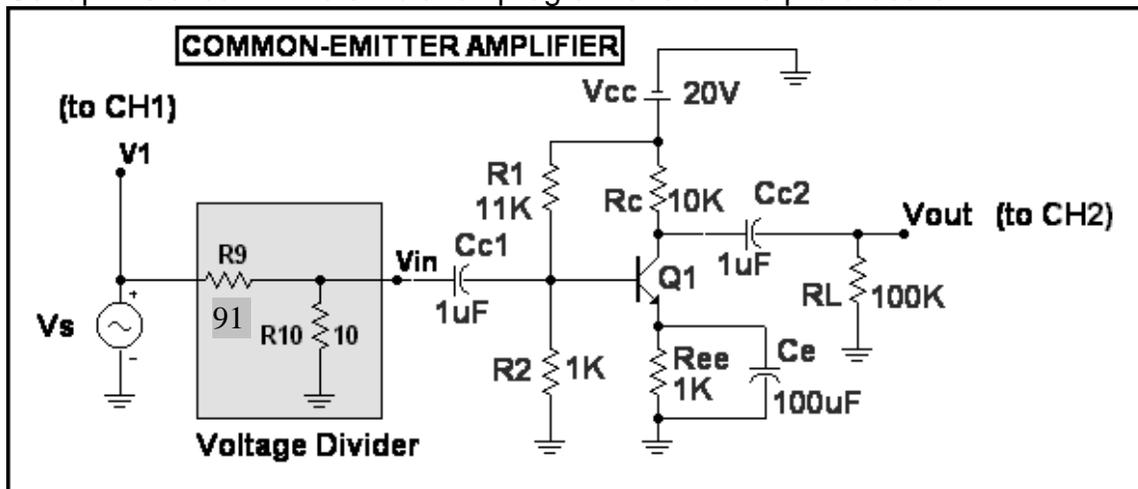
Ctrl + E: Select Mode

Ctrl + T: Text Mode

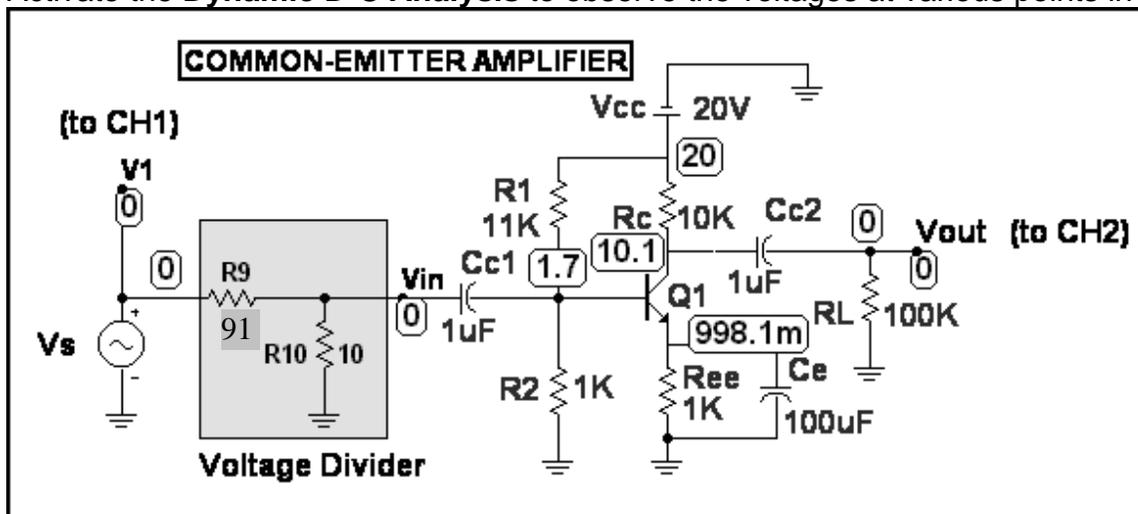
Ctrl + W: Straight Wire Mode

**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.

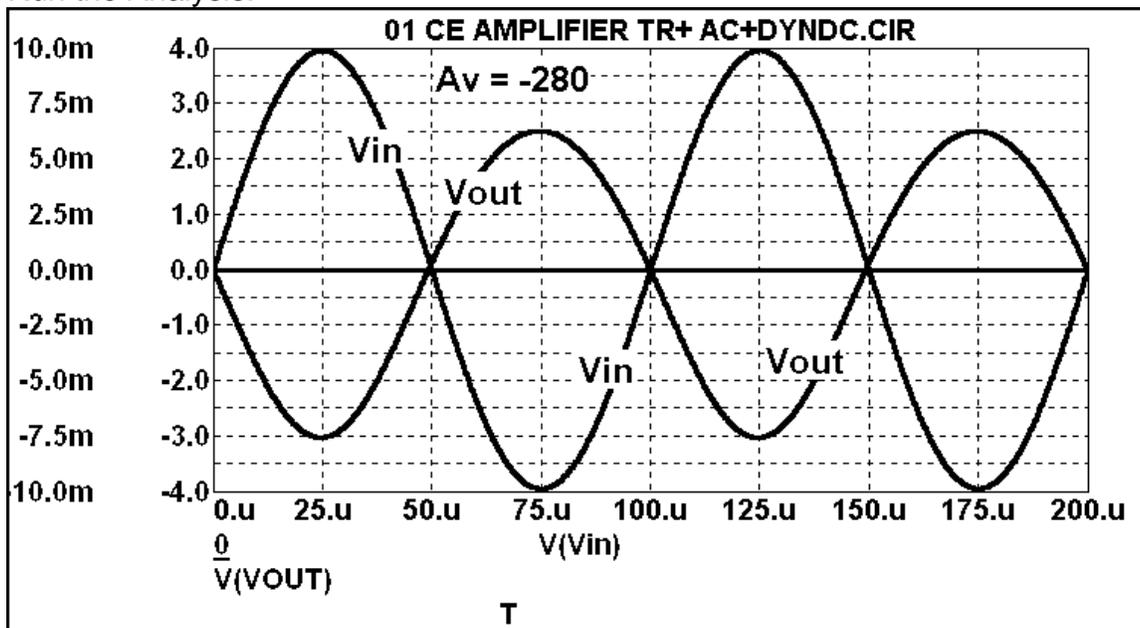
**Exp 1.2 Output Voltage and Voltage Gain**

Set the signal source to have an amplitude of 100 mV at  $f = 10$  kHz. This will result in  $V_{in}$  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**.

P	X Expression	Y Expression	X Range	Y Range
T	T	0	TMAX,TMIN,25	4,-4,0.5
T	V(Vin)	V(Vin)	TMAX,TMIN,25	10m,-10m,2.5m
T	V(VOUT)	V(VOUT)	TMAX,TMIN,25	4,-4,0.5

Run the Analysis.



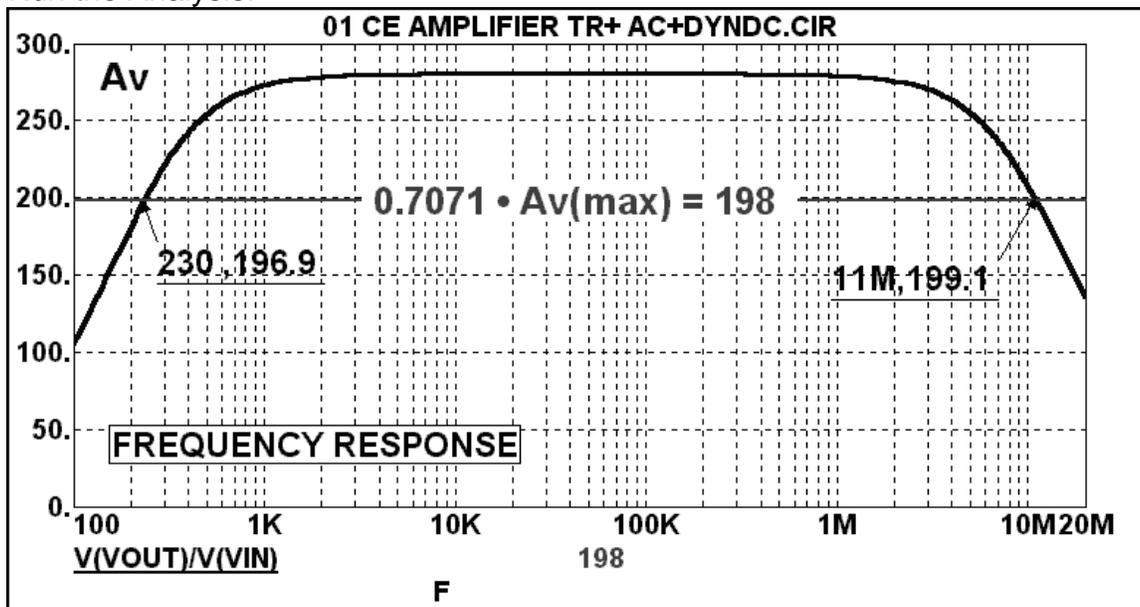
Determine the voltage gain.

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.

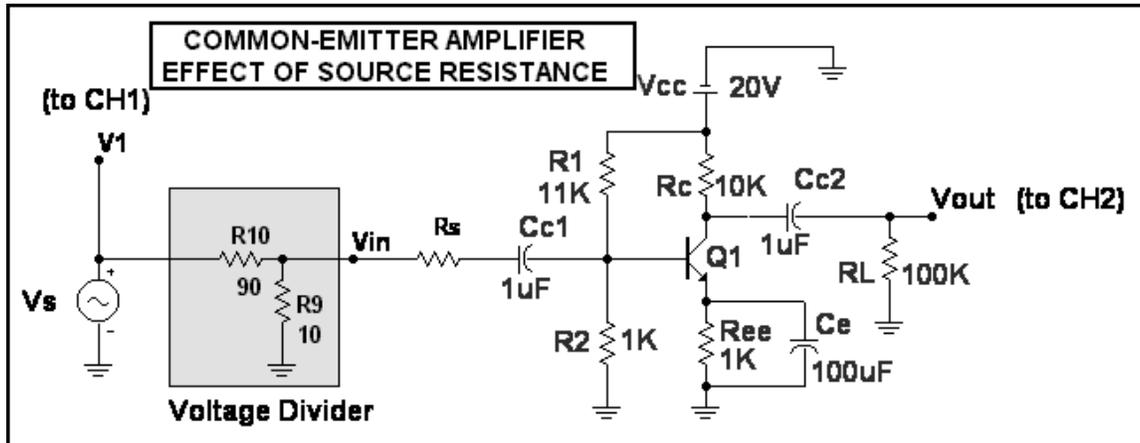
Run the Analysis.



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.

**Transient Analysis Limits**

Run Add Delete Expand... Stepping... Properties... Help...

Time Range: 200us Run Options: Normal  
 Maximum Time Step: 200ns 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	0	TMAX,TMIN,25	4,-4,0.5
1	T	V(Vin)	TMAX,TMIN,25	10m,-10m,2.5m
1	T	V(VOUT)	TMAX,TMIN,25	4,-4,0.5

Here are the Stepping Settings.

**Stepping**

1:RS.Value | 2: | 3: | 4: | 5: | 6: | 7: | 8: | 9: | 10:

Step What: RS Value

List: 0,300,1K

I<sub>o</sub>:

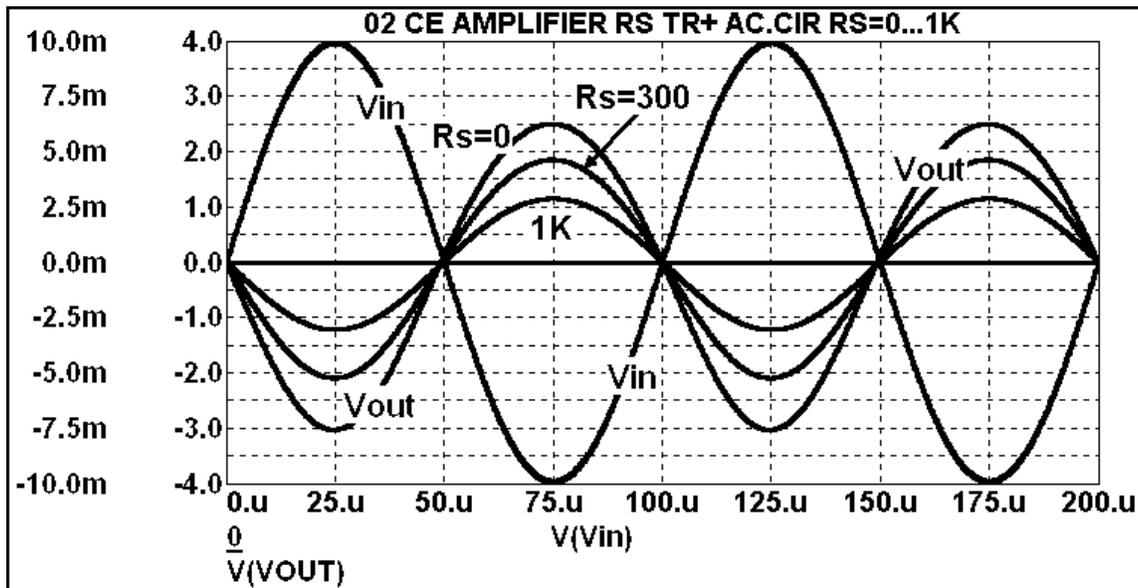
Step Value: 0

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. 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**

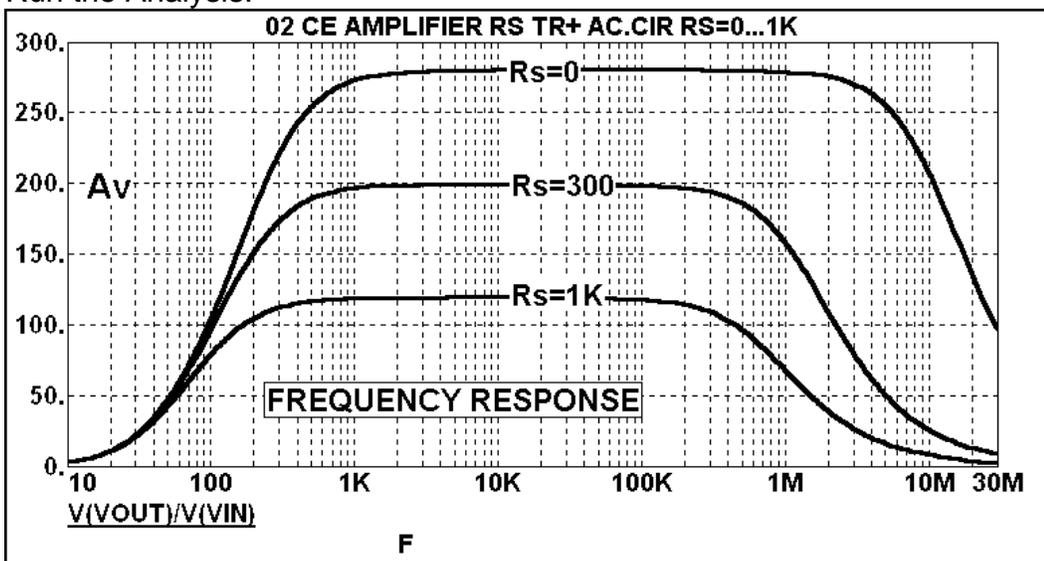
Use these A-C Analysis Limits.

AC Analysis Limits						
Run	Add	Delete	Expand...	Stepping...	Properties...	Help...
Frequency Range	30Meg, 10	Run Options	Normal			
Number of Points	50	State Variables	Zero			
Temperature	Linear	27	Frequency Step	Auto		
Maximum Change %	1	<input checked="" type="checkbox"/> Operating Point	<input type="checkbox"/> Auto Scale Ranges			
Noise Input	1					
Noise Output	2					
P		X Expression	Y Expression	X Range	Y Range	
T		F	V(VOUT)/V(VIN)	FMAX,FMIN	300,0,50	

Here are the Stepping Settings.

Stepping										
1:RS.Value	2:	3:	4:	5:	6:	7:	8:	9:	10:	
Step What	RS									
List	0,300,1K									
To										
Step Value	0									
Step It	<input checked="" type="radio"/> Yes <input type="radio"/> No		Method			Parameter Type				
			<input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List			<input checked="" type="radio"/> Component <input type="radio"/> Model				

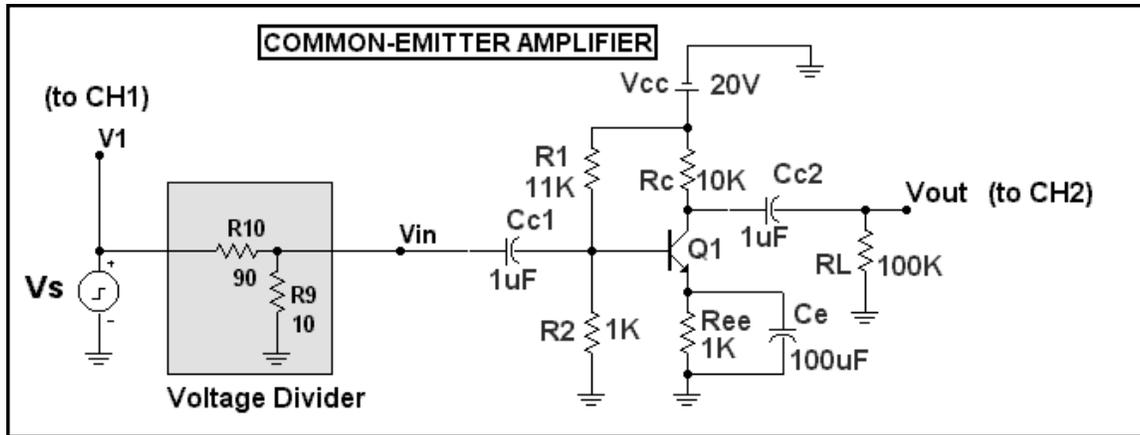
Run the Analysis.



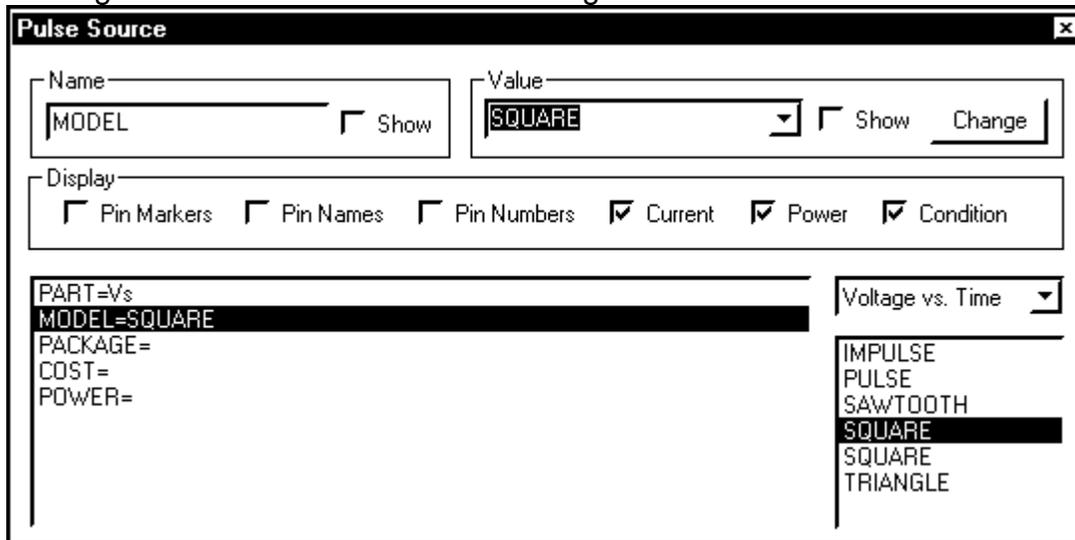
Find the frequencies at which the gain is down from its maximum or mid-frequency value by a factor of 1 over the square root of 2 = 0.7071. Find the corresponding frequencies in the actual circuit and compare the results with the simulation.

**Exp 1.6 Time-Domain Response to a Pulse Input**

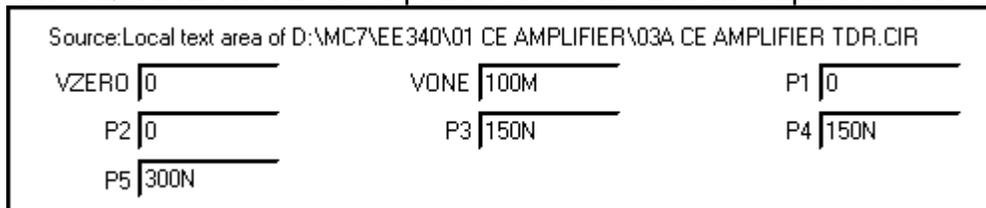
Change the signal source from a sine wave to a square wave in the simulation program and on the proto-board.



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**.

**Transient Analysis Limits**

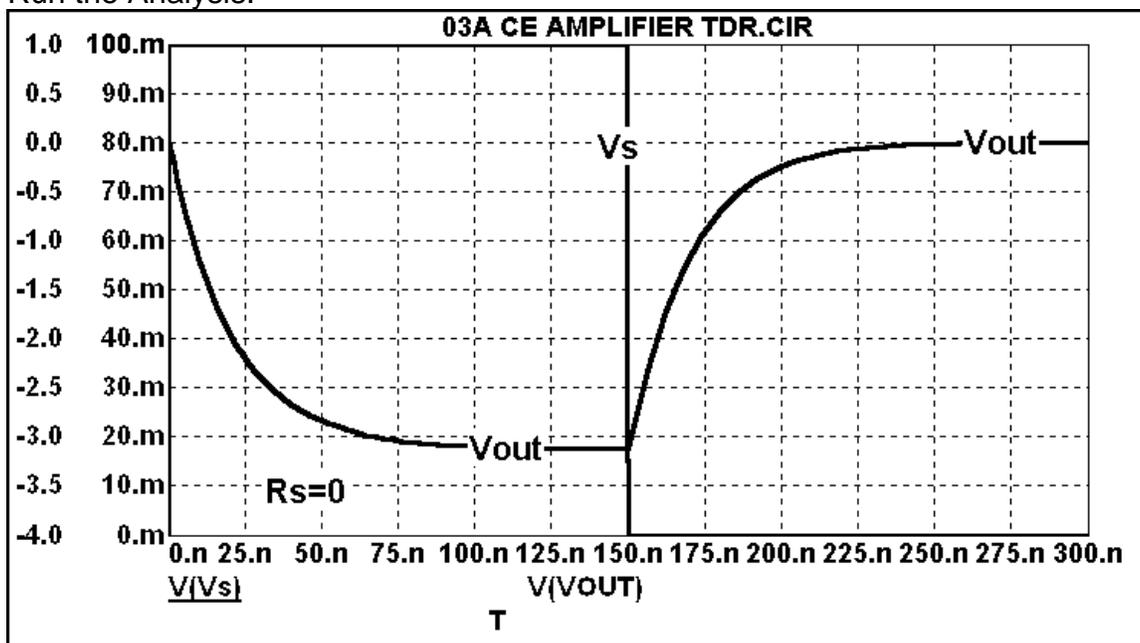
Run | Add | Delete | Expand... | Stepping... | Properties... | Help...

Time Range: 300n  
 Maximum Time Step: 0  
 Number of Points: 50  
 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	V(Vs)	TMAX,TMIN,25	100m,0,10m
1	T	V(VOUT)	TMAX,TMIN	1,-4,0.5

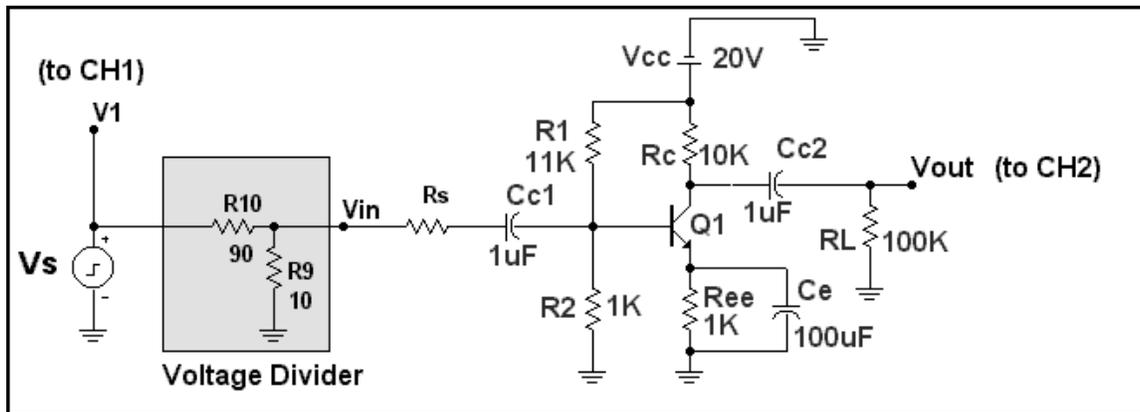
Run the Analysis.



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  $R_s$  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.



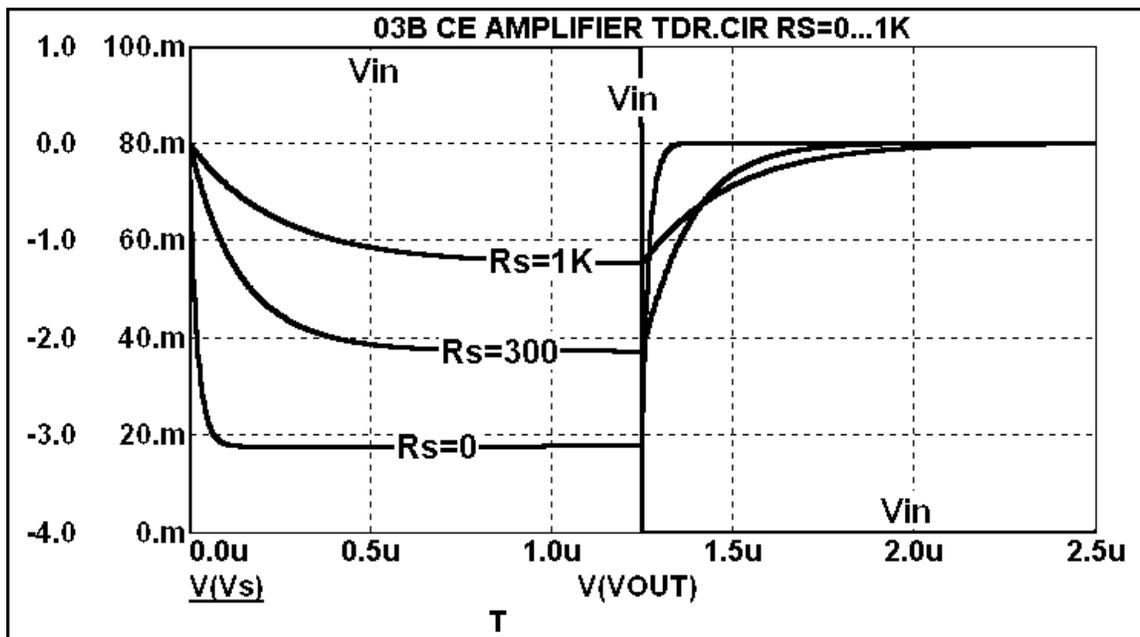
Use these **Transient Analysis Limits**.

Transient Analysis Limits													
Run		Add		Delete		Expand...		Stepping...		Properties...		Help...	
Time Range	2.5us			Run Options	Normal								
Maximum Time Step	2.5ns			State Variables	Zero								
Number of Points	50			<input checked="" type="checkbox"/> Operating Point									
Temperature	Linear			<input type="checkbox"/> Operating Point Only									
	27			<input type="checkbox"/> Auto Scale Ranges									
	P	X Expression		Y Expression		X Range		Y Range					
	1	V(Vs)		V(Vs)		TMAX,TMIN		100m,0					
	1	V(VOUT)		V(VOUT)		TMAX,TMIN		1,-4					

Here are the **Stepping Settings**.

Stepping										
1:RS.Value	2:	3:	4:	5:	6:	7:	8:	9:	10:	
Step What	RS Value									
List	0,300,1K									
Io										
Step Value	0									
Step It	<input checked="" type="radio"/> Yes <input type="radio"/> No		Method			Parameter Type				
			<input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List			<input checked="" type="radio"/> Component <input type="radio"/> Model				

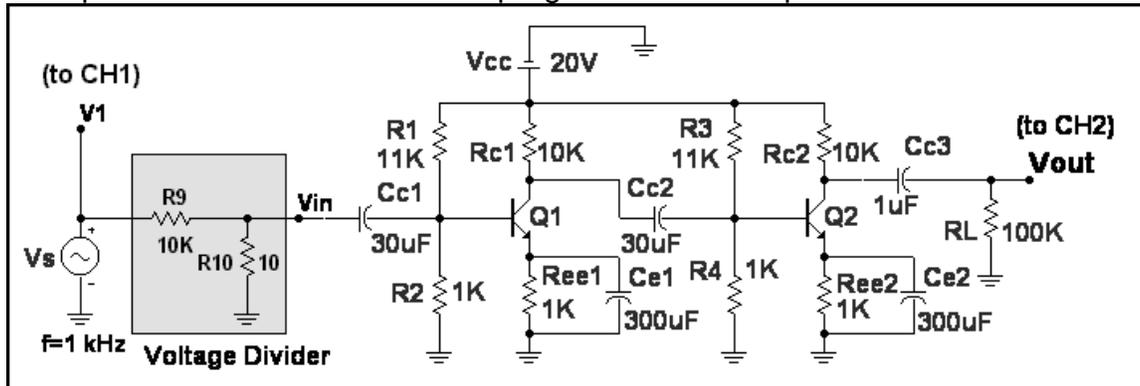
Run the Analysis.



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

**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**.

**Transient Analysis Limits**

Run   Add   Delete   Expand...   Stepping...   Properties...   Help...

Time Range: 2ms   Run Options: Normal

Maximum Time Step: 0   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	VE(Q2)	TMAX,TMIN,0	22,-0.2
1	T	VC(Q2)	TMAX,TMIN,0	22,-0.2
1	T	V(Vcc)	TMAX,TMIN,0	22,-0.2

Here are the **Stepping Settings**.

**Stepping**

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

Step What: VS   A

From: 1V

To: 8V

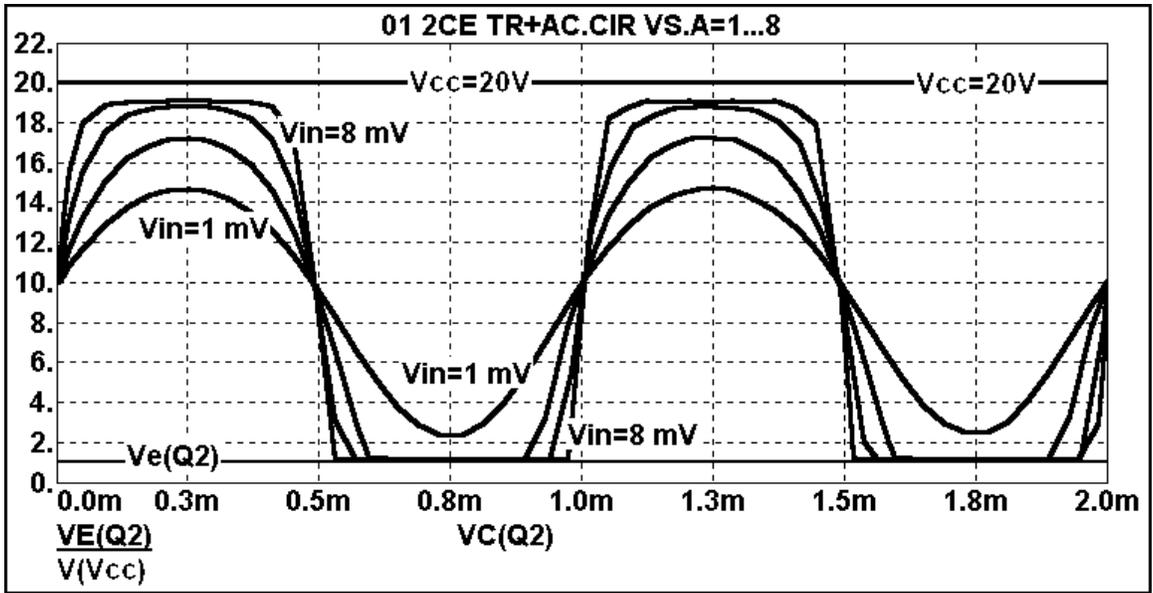
Step Value: 2

Step It:  Yes    No

Method:  Linear    Log    List

Parameter Type:  Component    Model

Run the Analysis.



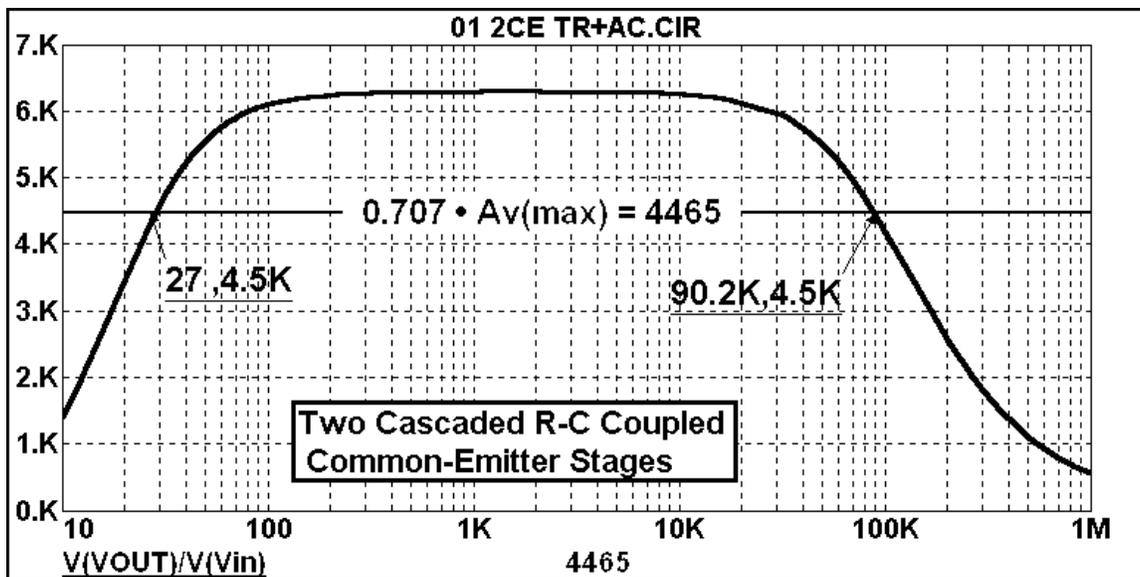
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

**Exp 2.2 Frequency Response Two-Stage Cascaded Amplifier**

Use these A-C Analysis Limits.

AC Analysis Limits							
Run		Add	Delete	Expand...	Stepping...	Properties...	Help...
Frequency Range	1Meg, 10		Run Options	Normal			
Number of Points	50		State Variables	Zero			
Temperature	Linear	27	Frequency Step	Auto			
Maximum Change %	5		<input checked="" type="checkbox"/> Operating Point				
Noise Input	1		<input type="checkbox"/> Auto Scale Ranges				
Noise Output	2						
P	X Expression	Y Expression	X Range	Y Range			
1	F	V(VOUT)/V(Vin)	FMAX,FMIN	7K,0,1K			
1	F	4465	FMAX,FMIN	7K,0,1K			

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**

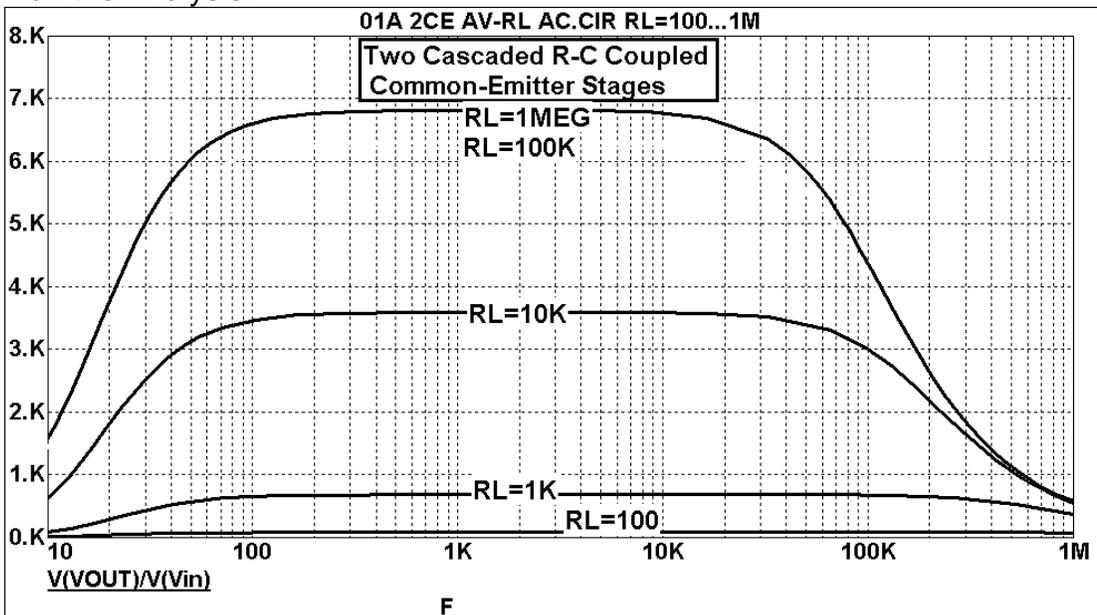
Use these A-C Analysis Limits.

AC Analysis Limits					
Run	Add		Stepping...	Properties...	Help...
Frequency Range	1Meg, 10		Run Options	Normal	
Number of Points			State Variables	Zero	
Temperature	Linear	27	Frequency Step	Auto	
Maximum Change %	5		<input type="checkbox"/>		
Noise Input	1		<input type="checkbox"/> Auto Scale Ranges		
Noise Output	2				
	P	X Expression	Y Expression	X Range	Y Range
	1	F	V(VOUT)/V(Vin)	FMAX,FMIN	8K,0.1K

Here are the Stepping Settings.

1:RL Value	2:	3:	4:	5:	6:	7:	8:	9:	10:	11:
Step What	RL									Value
From	100									
To	1MEG									
Step Value	10									
Step It	Method		Parameter Type							
<input checked="" type="radio"/> Yes	<input type="radio"/> No	<input type="radio"/> Linear	<input checked="" type="radio"/> Log	<input type="radio"/> List	<input checked="" type="radio"/> Component	<input type="radio"/> Model				

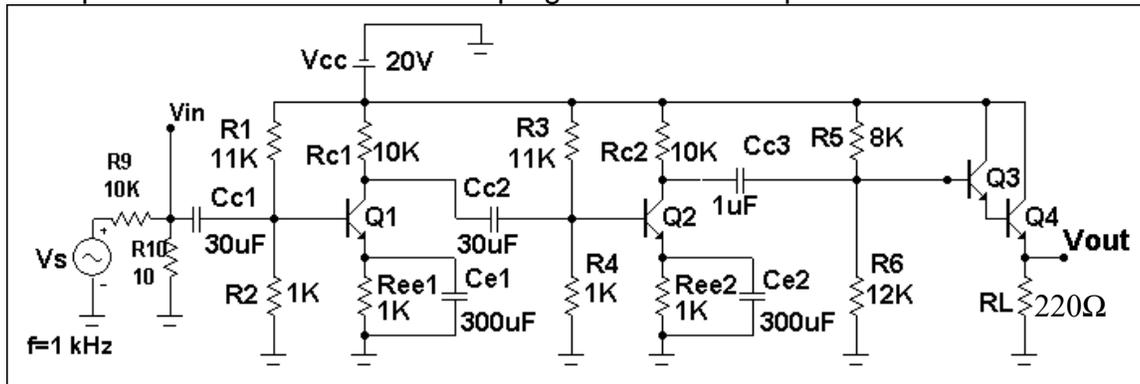
Run the Analysis.



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**.

**Transient Analysis Limits**

Run Add Stepping... Properties... Help...

Time Range: 12ms Run Options: Normal

Maximum Time Step: 12us State Variables: Zero

Number of Points: Operating Point (checked)

Temperature: Linear 27 Operating Point Only (unchecked)

Auto Scale Ranges (unchecked)

P	X Expression	Y Expression	X Range	Y Range
1	V	V(Vout)	10m,8m,0.25m	12V,0.1V

Here are the **Stepping Settings**.

**Stepping**

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

Step What: VS A

From: 1V

To: 4V

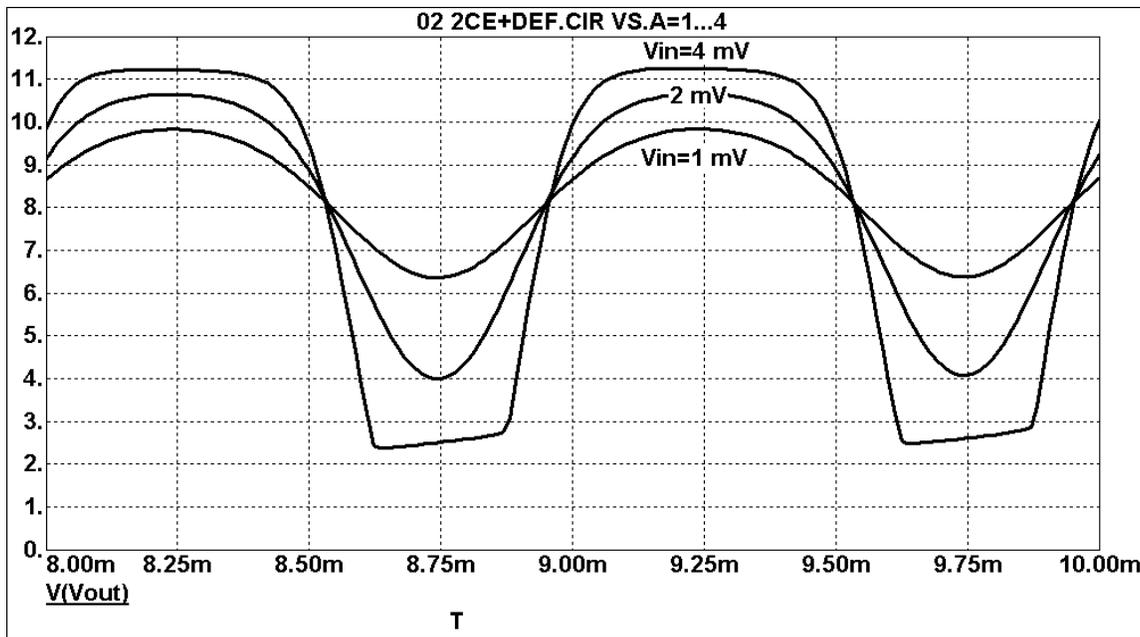
Step Value: 2

Step It: Yes (checked) No

Method: Linear (unchecked) Log (checked) List

Parameter Type: Component (checked) Model

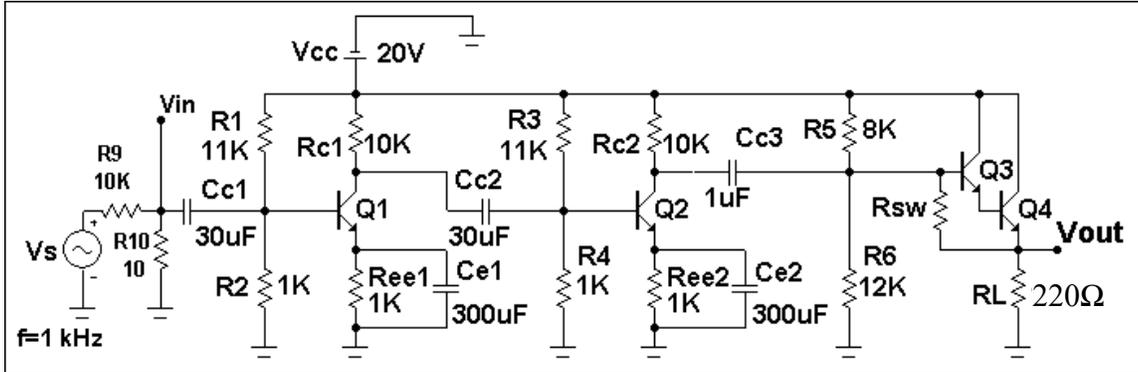
Run the Analysis.



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 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  $1\text{ K}\Omega$ .



Use these **Transient Analysis Limits**.

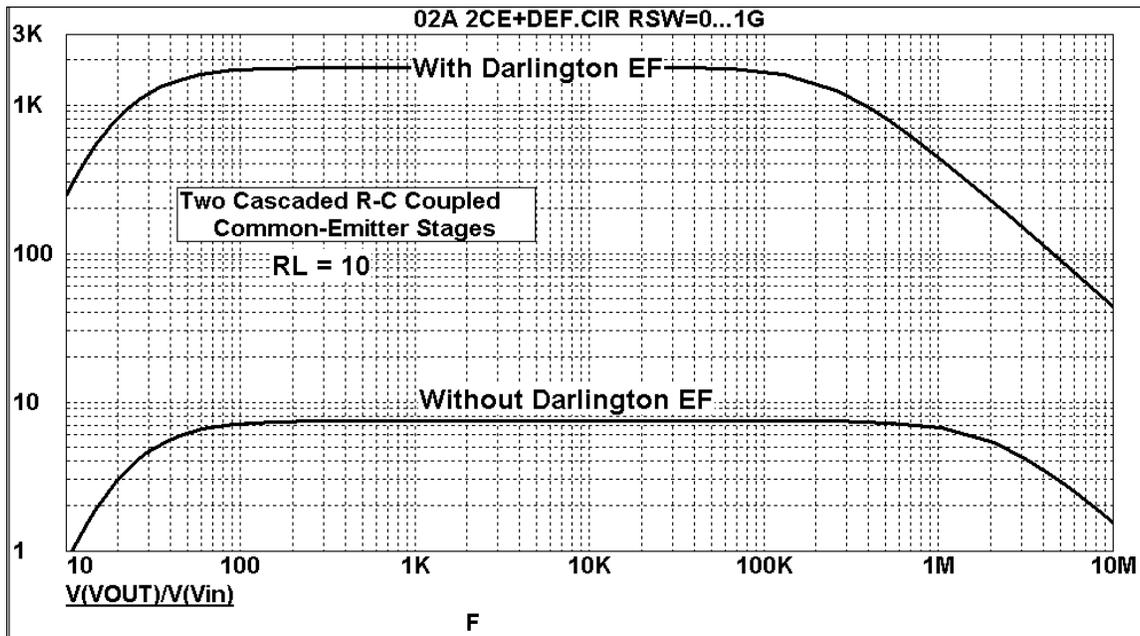
AC Analysis Limits				
Run	Add	Stepping...	Properties...	Help...
Frequency Range	10Meg, 10	Run Options	Normal	
Number of Points		State Variables	Zero	
Temperature	Linear 27	Frequency Step	Auto	
Maximum Change %	5			
Noise Input	1			
Noise Output	2			
	P	X Expression	Y Expression	X Range Y Range
	1	F	V(VOUT)/V(Vin)	FMAX,FMIN 3K1

Here are the **Stepping Settings**.

Stepping									
1:RSW.Value	2:	3:	4:	5:	6:	7:	8:	9:	10:
Step What	RSW								
List	1G,0								
Step It	Method		Parameter Type						
<input checked="" type="radio"/> Yes	<input type="radio"/> No	<input type="radio"/> Linear	<input type="radio"/> Log	<input checked="" type="radio"/> List	<input checked="" type="radio"/> Component	<input type="radio"/> Model			

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

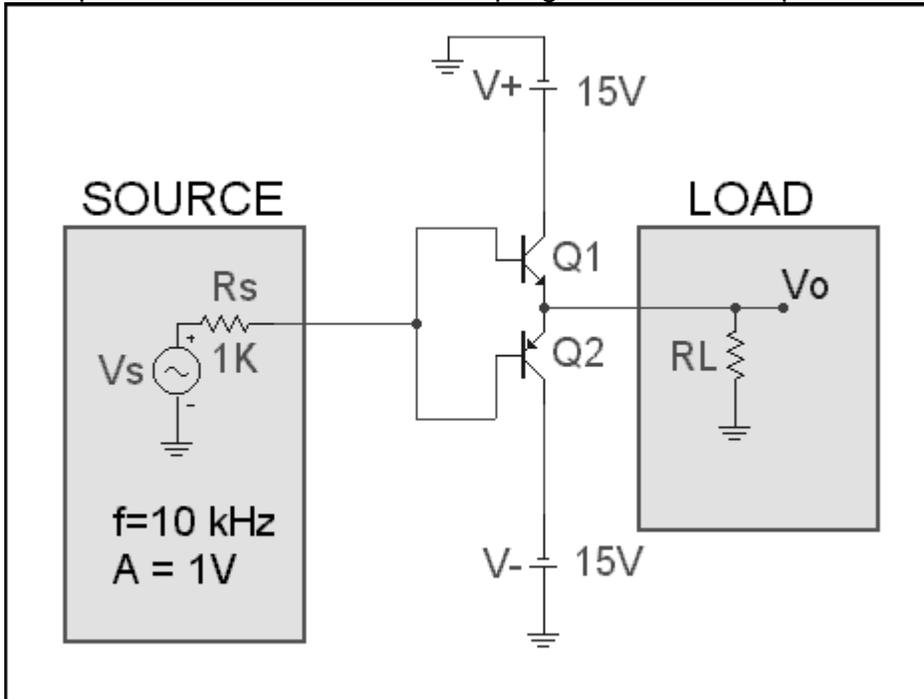
Run the Analysis.



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 Q2 can be any suitable PNP transistor such as a 2N3906.

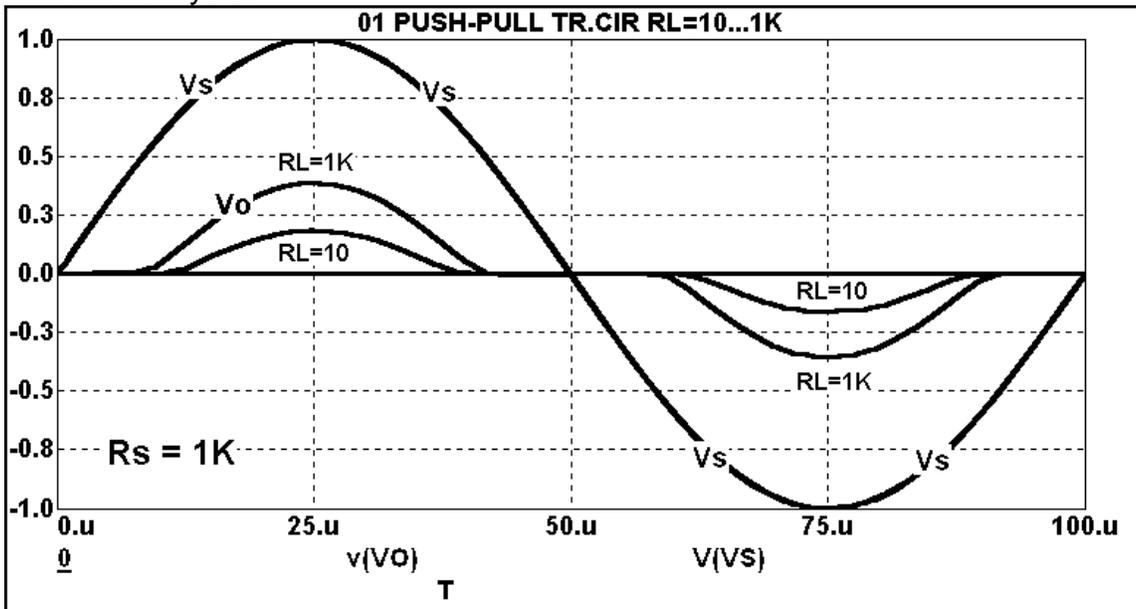
Use these **Transient Analysis Limits**.

Run		Add	Delete	Expand...	Stepping...	Properties...	Help...
Time Range	100u	Run Options	Normal				
Maximum Time Step	0	State Variables	Zero				
Number of Points	51	<input checked="" type="checkbox"/> Operating Point					
Temperature	Linear	<input type="checkbox"/> Operating Point Only					
	27	<input type="checkbox"/> Auto Scale Ranges					
P	X Expression	Y Expression	X Range	Y Range			
1	T	0	TMAX,TMIN,25	1,-1,0.25			
1	T	v(V0)	TMAX,TMIN	1,-1,0.25			
1	T	v(VS)	TMAX,TMIN	1,-1,0.25			

Here are the **Stepping Settings**.

1:RL.Value	2:	3:	4:	5:	6:	7:	8:	9:	10:
Step What	RL								
List	10,1K								
I <sub>o</sub>	160								
Step Value	2								
Step It	<input checked="" type="radio"/> Yes <input type="radio"/> No			Method			Parameter Type		
				<input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List			<input checked="" type="radio"/> Component <input type="radio"/> 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 the “crossover distortion” in the region where both transistors are off.

**Exp 3.2 Voltage Transfer Curve**

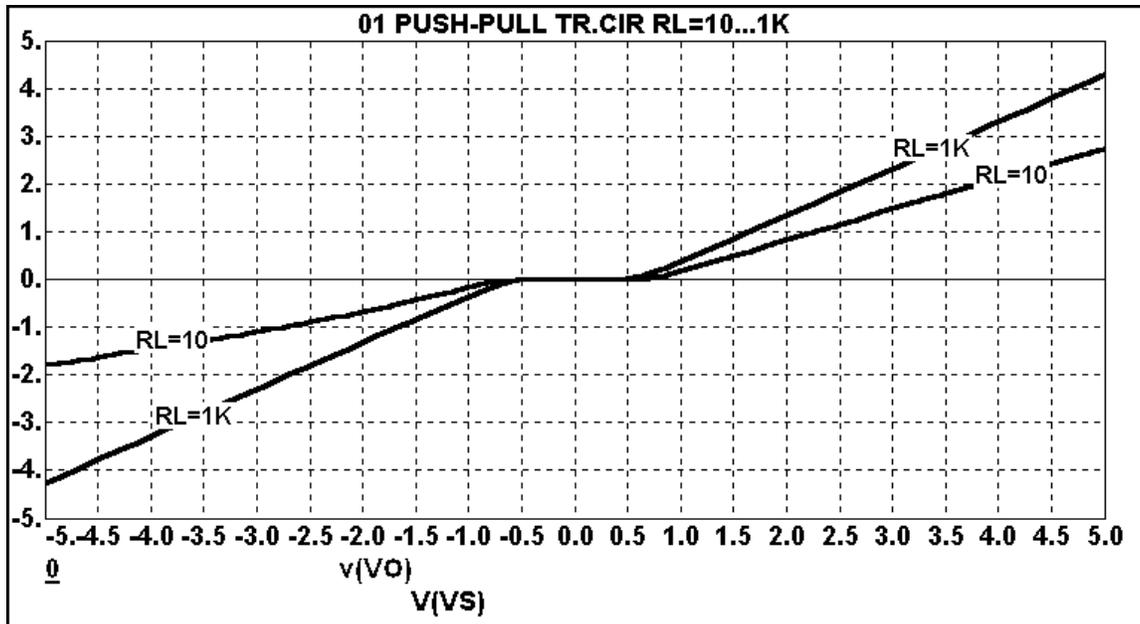
Use these **D-C Analysis Limits**.

Run	Add	Delete	Expand...	Stepping...	Properties...	Help...
Sweep						
Variable 1	Method	Name	Range			
Auto	VS		5,-5			
Variable 2	Method	Name	Range			
None						
Temperature		Number of Points		Maximum Change %		
Method	Range					
Linear	27	51		5		
Run Options		Auto Scale Ranges				
Normal		<input type="checkbox"/>				
	P	X Expression	Y Expression	X Range	Y Range	
	1	DCINPUT1	0	5,-5,1	5,-5,1	
	1	DCINPUT1	v(V0)	5,-5,1	5,-5,1	

Here are the **Stepping Settings**.

Run	Add	Delete	Expand...	Stepping...	Properties...	Help...
Sweep						
Variable 1	Method	Name	Range			
Auto	VS		5,-5			
Variable 2	Method	Name	Range			
None						
Temperature		Number of Points		Maximum Change %		
Method	Range					
Linear	27	51		5		
Run Options		Auto Scale Ranges				
Normal		<input type="checkbox"/>				
	P	X Expression	Y Expression	X Range	Y Range	
	1	DCINPUT1	0	5,-5,0.5	5,-5,1	
	1	DCINPUT1	v(V0)	5,-5,0.5	5,-5,1	

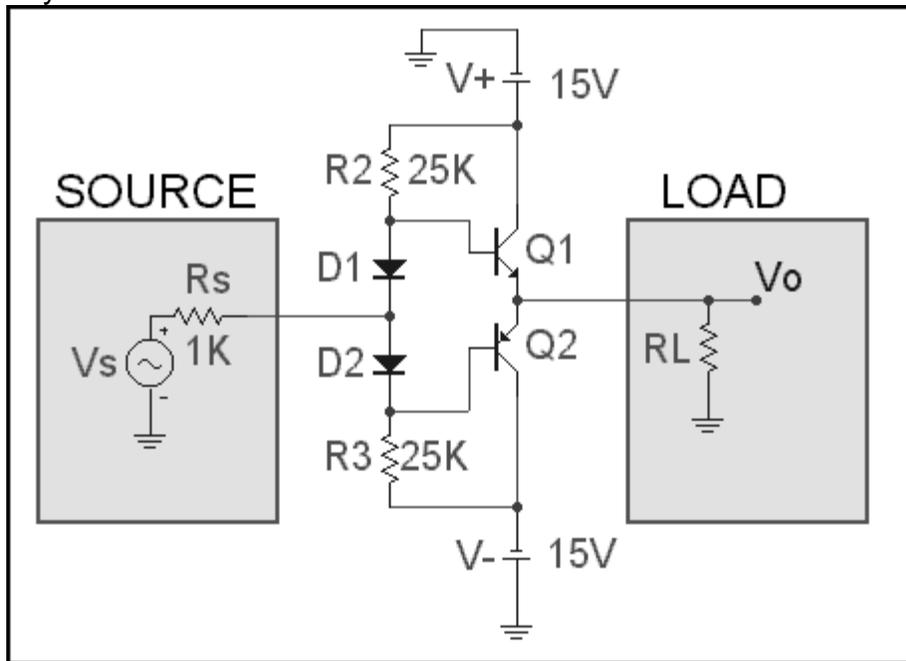
Run the Analysis.



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.



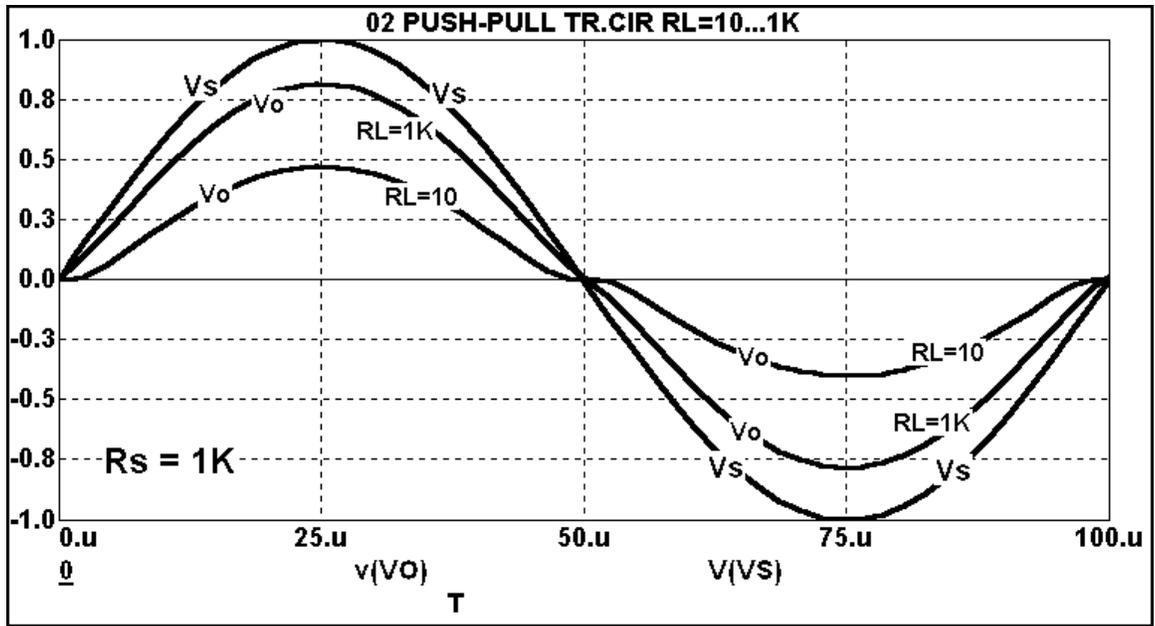
Use these **Transient Analysis Limits**.

Run	Add	Delete	Expand...	Stepping...	Properties...	Help...
Time Range	100u	Run Options	Normal			
Maximum Time Step	0	State Variables	Zero			
Number of Points	51	<input checked="" type="checkbox"/> Operating Point				
Temperature	Linear	<input type="checkbox"/> Operating Point Only				
	27	<input type="checkbox"/> Auto Scale Ranges				
P	X Expression	Y Expression	X Range	Y Range		
	T	0	TMAX,TMIN,25	1,-1,0.25		
	T	v(V0)	TMAX,TMIN	1,-1,0.25		
	T	v(VS)	TMAX,TMIN	1,-1,0.25		

Here are the **Stepping Settings**.

1:RL.Value	2:	3:	4:	5:	6:	7:	8:	9:	10:
Step w/hat	RL	Value							
List	10,1K								

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**

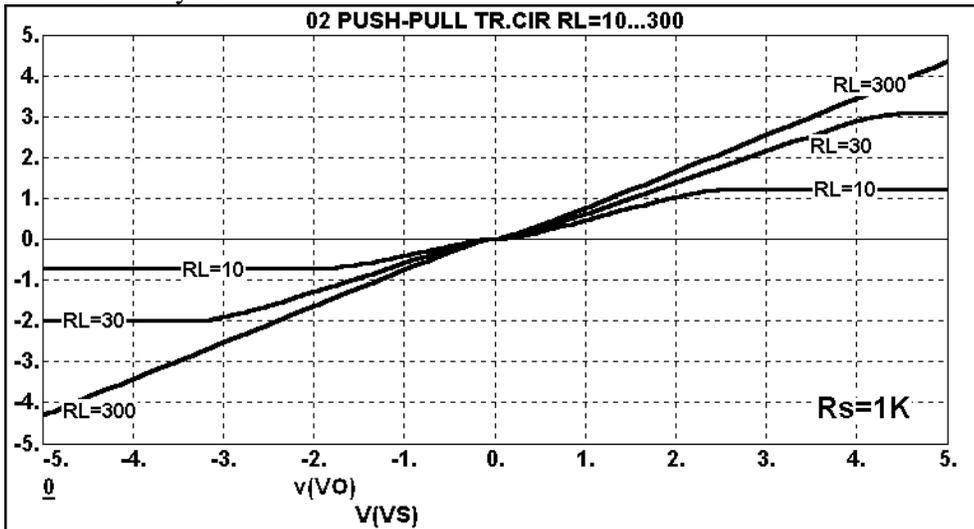
Use these D-C Analysis Limits.

Run	Add	Delete	Expand...	Stepping...	Properties...	Help...
Sweep						
Variable 1	Method	Name	Range			
Variable 2	Method	Name	Range			
Temperature Method		Range	Number of Points	Maximum Change %		
Linear		27	51	5		
Run Options: Normal <input type="checkbox"/> Auto Scale Ranges						
	P	X Expression	Y Expression	X Range	Y Range	
	1	DCINPUT1	0	5,-5.1	5,-5.1	
	1	DCINPUT1	v(V0)	5,-5.1	5,-5.1	

Here are the Stepping Settings.

1: RL Value	2:	3:	4:	5:	6:	7:	8:	9:	10:
Step What	RL								
List	10,30,300								
To									
Step Value									
Step It	Method		Parameter Type						
<input checked="" type="radio"/> Yes <input type="radio"/> No	<input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List		<input checked="" type="radio"/> Component <input type="radio"/> Model						

Run the Analysis.

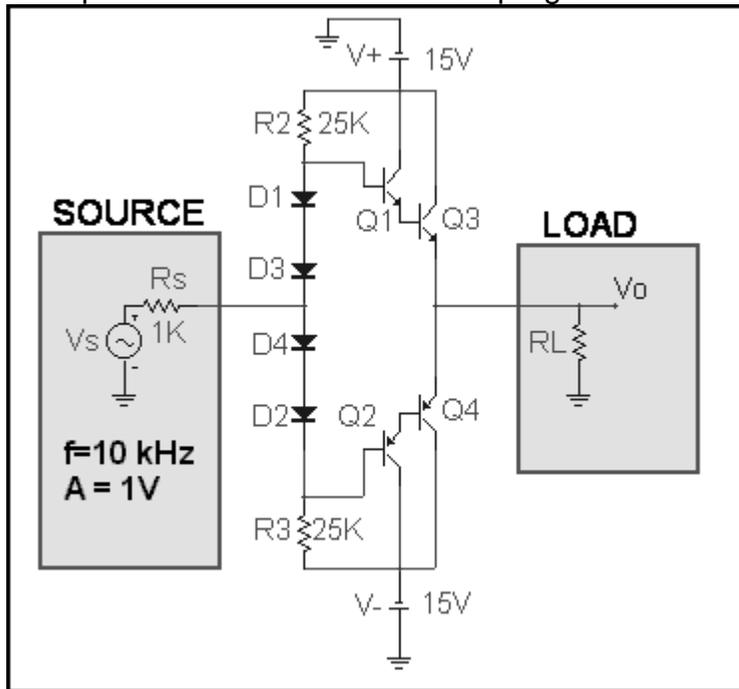


Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. What is the width of the “crossover distortion” region where both transistors are off?

# PUSH-PULL CIRCUITS Using Darlington Emitter-Followers **EXPERIMENT 3.5**

## 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	Run Options	Normal
Maximum Time Step	0	State Variables	Zero
Number of Points	51	<input checked="" type="checkbox"/> Operating Point	
Temperature	Linear	<input type="checkbox"/> Operating Point Only	
	27	<input type="checkbox"/> Auto Scale Ranges	

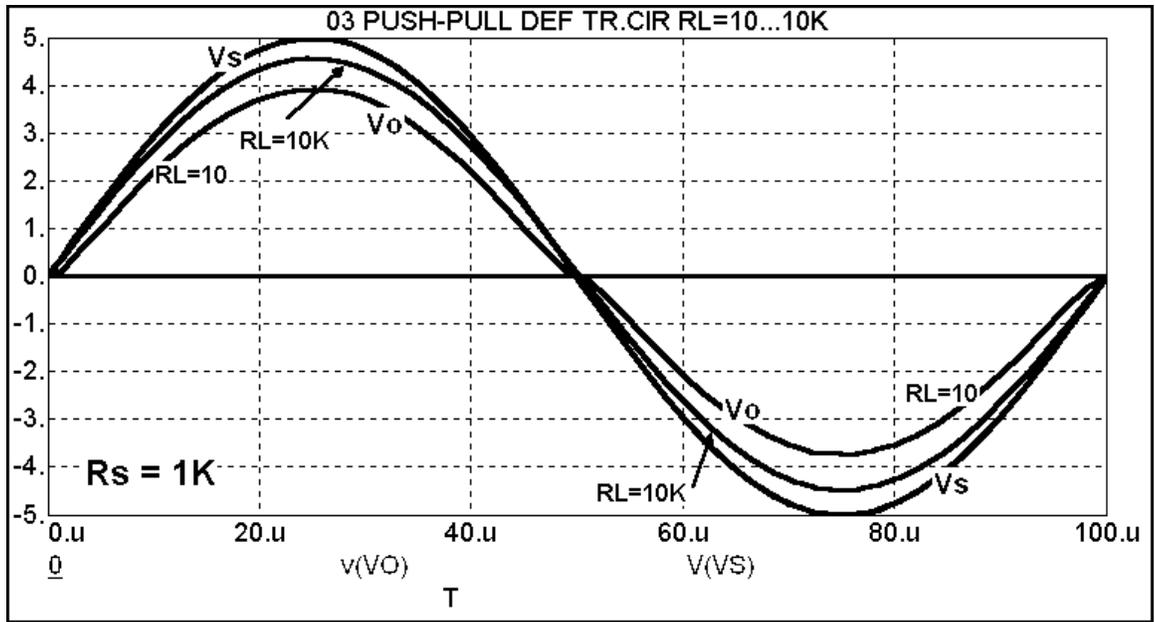
P	X Expression	Y Expression	X Range	Y Range
1	T	0	TMAX,TMIN	5,-5,1
1	T	v(VO)	TMAX,TMIN	5,-5,1
1	T	v(VS)	TMAX,TMIN	5,-5,1

Here are the **Stepping Settings**.

Step What	RL	Value
List	10,10K	
Io	160	
Step Value	2	
Step It	Method	Parameter Type
<input checked="" type="radio"/> Yes <input type="radio"/> No	<input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List	<input checked="" type="radio"/> Component <input type="radio"/> 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.

Sweep			
Variable	Method	Name	Range
Variable 1	Auto	V <sub>S</sub>	5,-5
Variable 2	None		

Temperature		Number of Points	Maximum Change %
Method	Range		
Linear	27	51	5

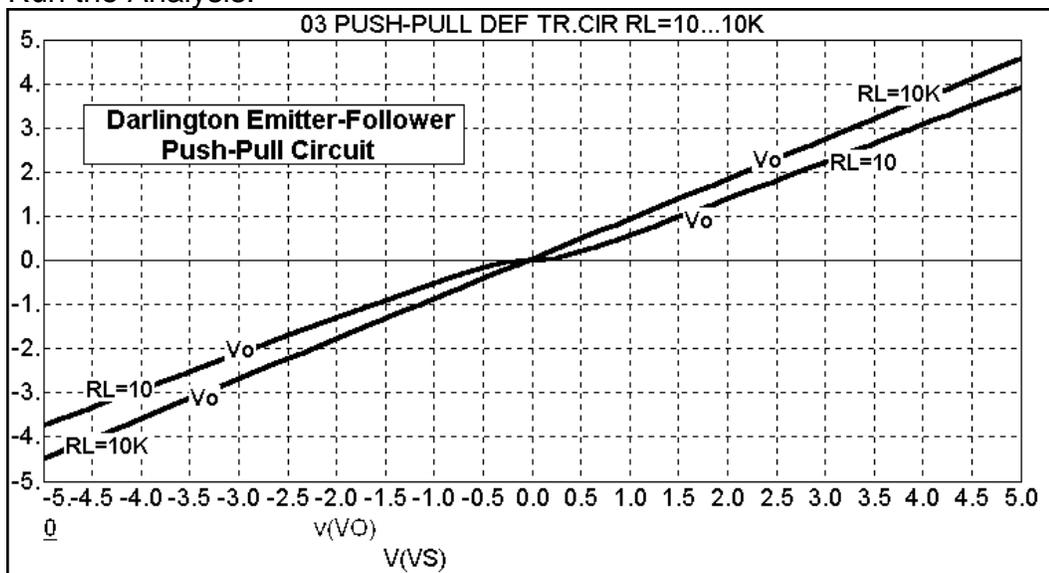
Run Options:  Normal  Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	DCINP1	0	5,-5,0.5	5,-5,1
1	DCINP1	v(VO)	5,-5,0.5	5,-5,1

Here are the Stepping Settings.

Step What	RL	Value
List	10,10K	
I <sub>o</sub>	160	
Step Value	2	
Step It	<input checked="" type="radio"/> Yes <input type="radio"/> No	
Method	<input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List	
Parameter Type	<input checked="" type="radio"/> Component <input type="radio"/> Model	

Run the Analysis.

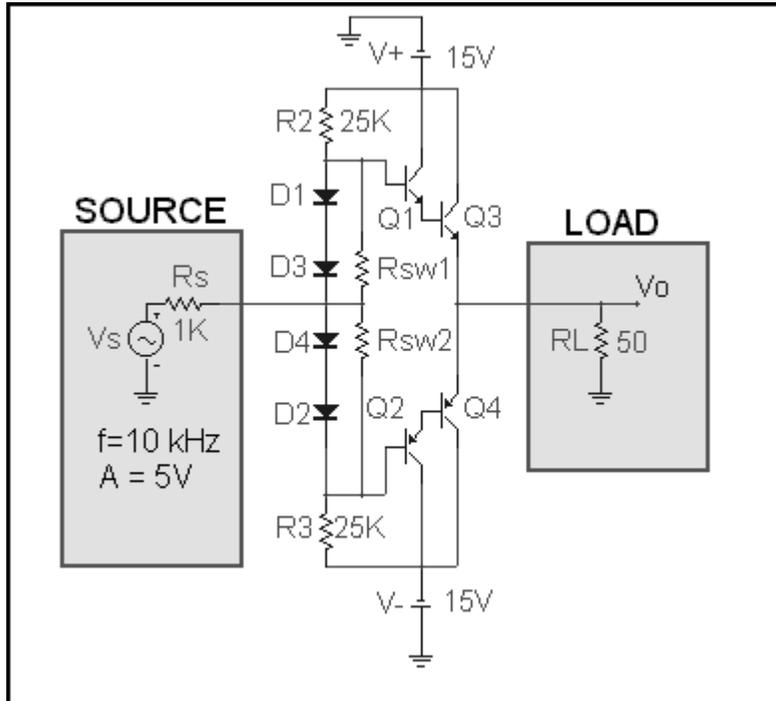


Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

# PUSH-PULL CIRCUITS Using Darlington Emitter-Followers EXPERIMENT 3.7

## 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**.

Resistor	
Name	Value
PART <input type="checkbox"/> Show	Rsw1
Display	
<input type="checkbox"/> Pin Markers	<input type="checkbox"/> Pin Names
<input type="checkbox"/> Pin Numbers	
PART=Rsw1	
VALUE=1	
FREQ=	
MODEL=RX	

Use these **Transient Analysis Limits**.

Time Range	100u	Run Options	Normal	
Maximum Time Step	0	State Variables	Zero	
Number of Points	51	<input checked="" type="checkbox"/> Operating Point		
Temperature	Linear	<input type="checkbox"/> Operating Point Only		
	27	<input type="checkbox"/> Auto Scale Ranges		
P	X Expression	Y Expression	X Range	Y Range
1	T	0	TMAX,TMIN,25	5,-5,1
1	T	v(V0)	TMAX,TMIN	5,-5,1
1	T	v(VS)	TMAX,TMIN	5,-5,1

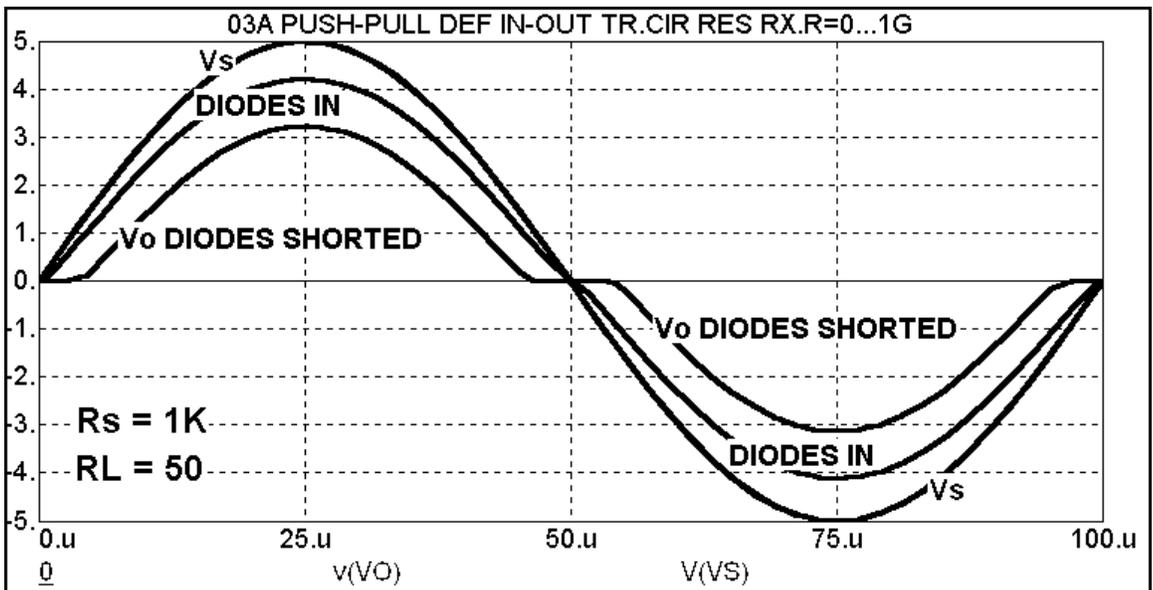
## PUSH-PULL CIRCUITS Using Darlington Emitter-Followers EXPERIMENT 3.7

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

1:RES RX.R	2:RSW2.Value	3:	4:	5:	6:	7:	8:	9:
Step What	RES RX							
List	0,1G							
Io	160							
Step Value	2							
Step It	Method		Parameter Type					
<input checked="" type="radio"/> Yes <input type="radio"/> No	<input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List		<input type="radio"/> Component <input checked="" type="radio"/> Model					

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  $1G\Omega$  (= 1000  $M\Omega$ ), 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**.

Sweep			
Variable	Method	Name	Range
Variable 1	Auto	V <sub>S</sub>	5,-5
Variable 2	None		

Temperature		Number of Points	Maximum Change %
Method	Range		
Linear	27	51	5

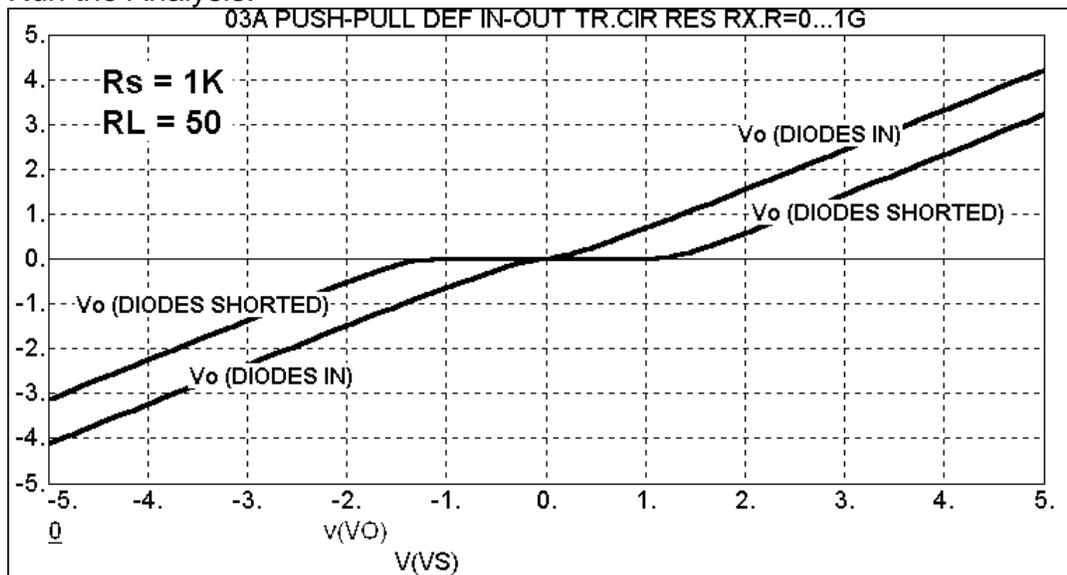
Run Options:  Normal  Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	DCINPUT1	0	5,-5,1	5,-5,1
1	DCINPUT1	v(VO)	5,-5,1	5,-5,1

Here are the **Stepping Settings** for resistors R<sub>SW1</sub> and R<sub>SW2</sub>.

1:RES RX,R	2:RSW2.Value	3:	4:	5:	6:	7:	8:	9:
Step What	RES RX							
List	0,1G							
I <sub>o</sub>	160							
Step Value	2							
Step It	<input checked="" type="radio"/> Yes <input type="radio"/> No		Method <input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List			Parameter Type <input type="radio"/> Component <input checked="" type="radio"/> Model		

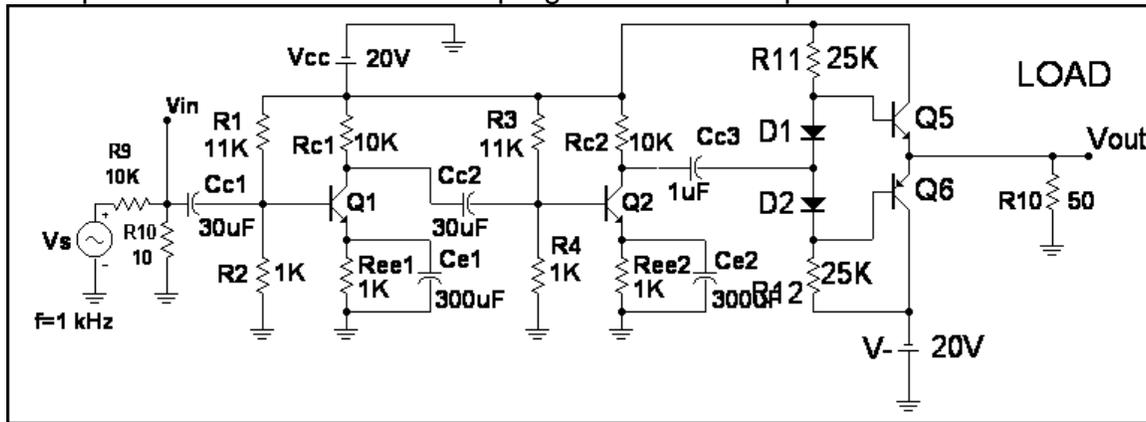
Run the Analysis.



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

**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**.

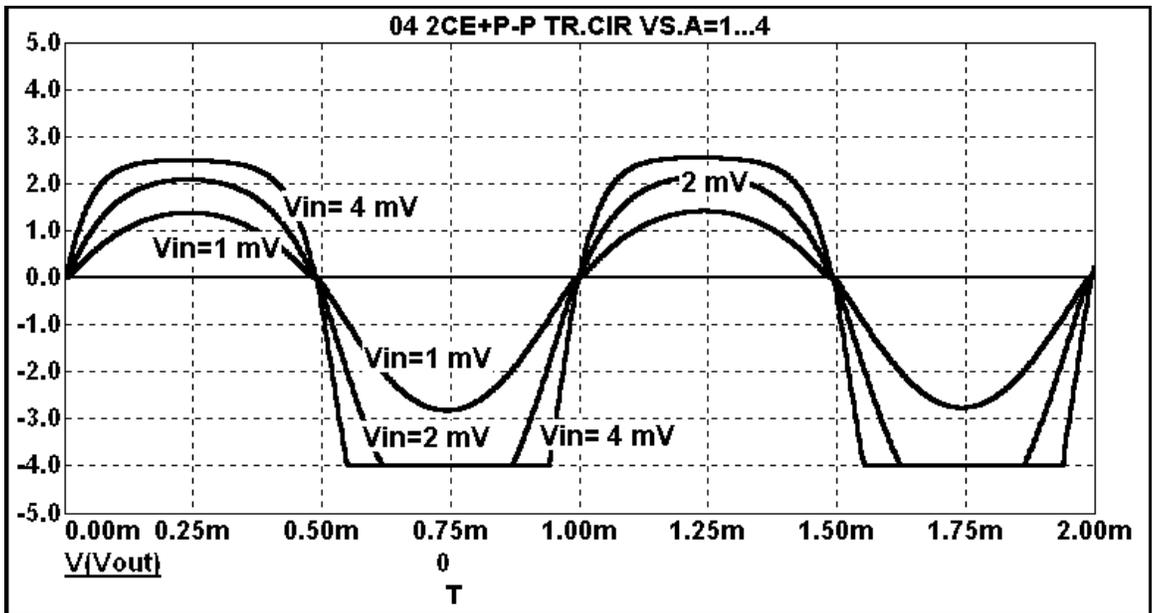
Time Range	2m	Run Options	Normal
Maximum Time Step	2u	State Variables	Zero
Number of Points	50	<input checked="" type="checkbox"/> Operating Point	
Temperature	Linear	<input type="checkbox"/> Operating Point Only	
	27	<input type="checkbox"/> Auto Scale Ranges	

P	X Expression	Y Expression	X Range	Y Range
1	V	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	<input checked="" type="radio"/> Yes <input type="radio"/> No	Method	<input type="radio"/> Linear <input checked="" type="radio"/> Log <input type="radio"/> List	Parameter Type	<input checked="" type="radio"/> Component <input type="radio"/> Model						

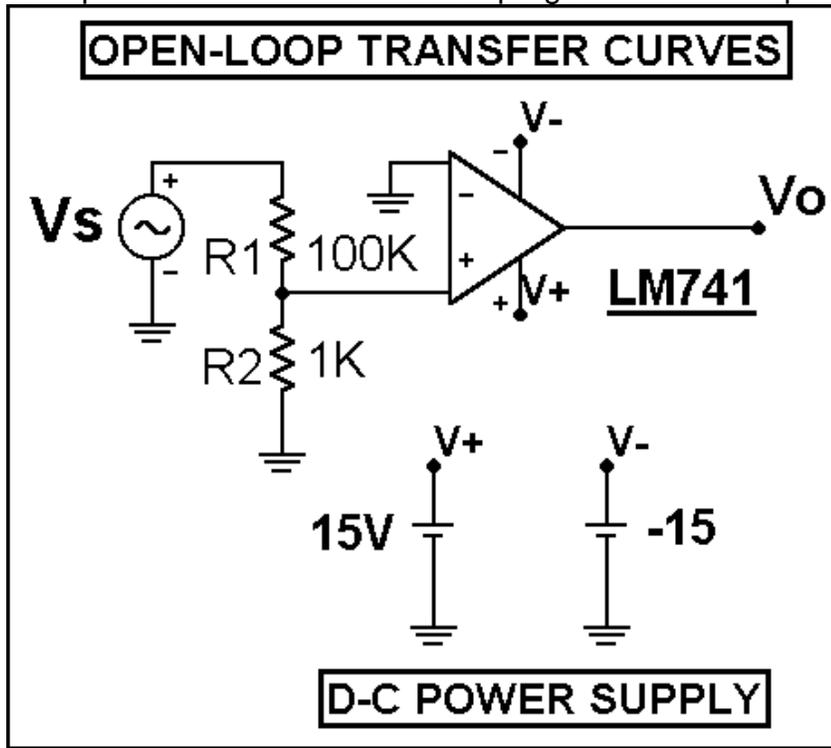
Run the Analysis.



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.

**DC Analysis Limits**

Run | Add | Delete | Expand... | Stepping... | Properties... | Help...

Sweep

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

Temperature

Method	Range
Linear	27

Number of Points: 51

Maximum Change %: 3

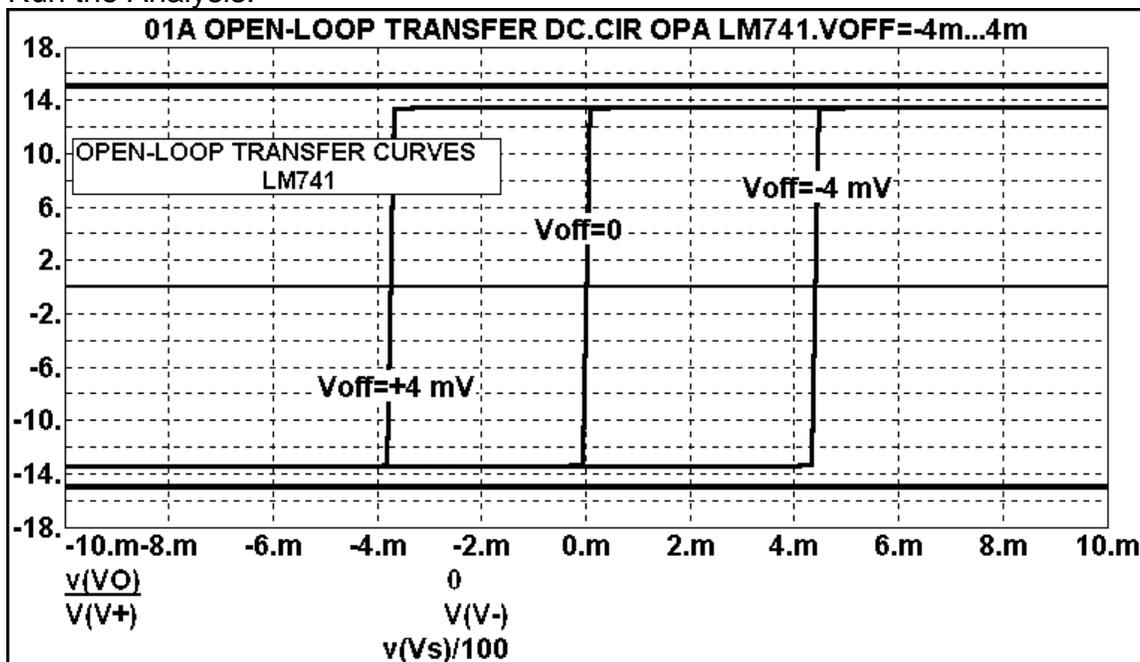
Run Options: Normal  Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	v(Vs)/100	v(VO)	10mV,-10mV,2	18V,-18,2V
1	v(Vs)/100	0	10mV,-10mV,2	18V,-18,2V
1	v(Vs)/100	V(V+)	10mV,-10mV,2	18V,-18,2V
1	v(Vs)/100	V(V-)	10mV,-10mV,2	18V,-18,2V

Here are the stepping settings:

Stepping							
1:OPA LM741.VOFF	2:A1.LEVEL	3:	4:	5:	6:	7:	8:
Step What	OPA LM741						VOFF
List	-4mV,0,+4mV						
To							
Step Value							
Step It		Method			Parameter Type		
<input checked="" type="radio"/> Yes	<input type="radio"/> No	<input type="radio"/> Linear	<input type="radio"/> Log	<input checked="" type="radio"/> List	<input type="radio"/> Component	<input checked="" type="radio"/> Model	

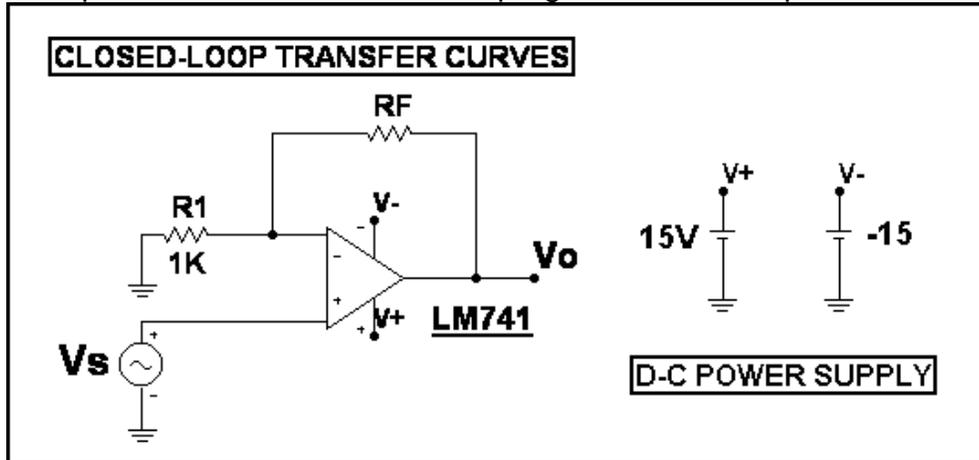
Run the Analysis.



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

**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.

**DC Analysis Limits**

Run Add Delete Expand... Stepping... Properties... Help...

Sweep

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

Temperature

Method	Range	Number of Points	Maximum Change %
Linear	27	51	3

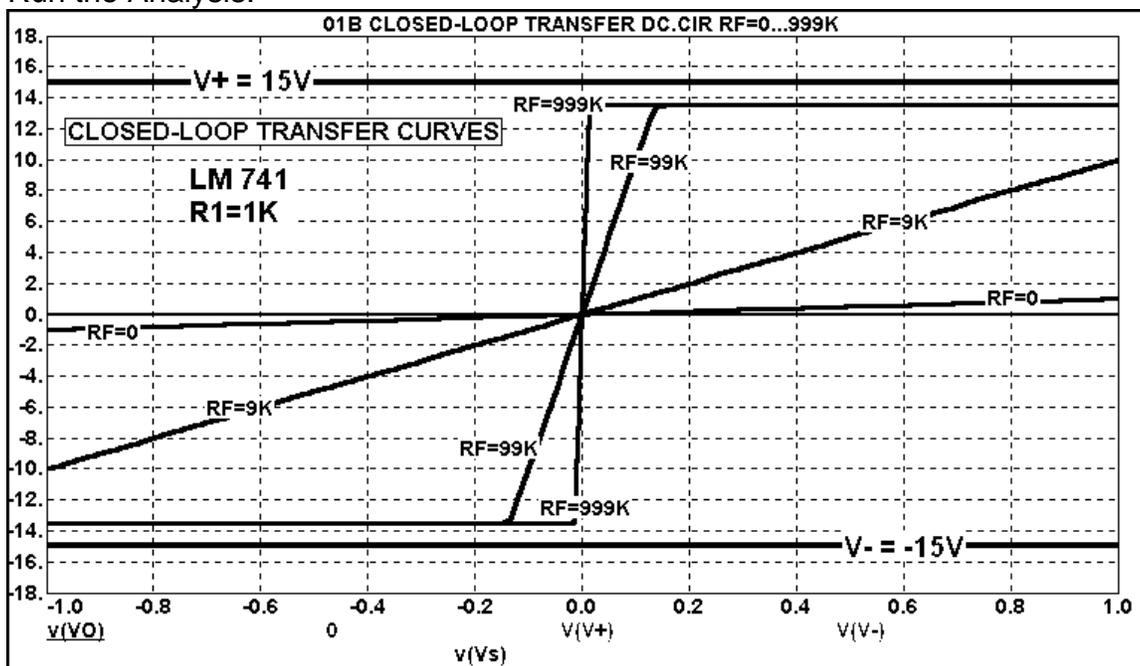
Run Options: Normal  Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	v(Vs)	v(VO)	1V,-1V,0.2V	18V,-18,2V
1	v(Vs)	0	1V,-1V,0.2V	18V,-18,2V
1	v(Vs)	v(V+)	1V,-1V,0.2V	18V,-18,2V
1	v(Vs)	v(V-)	1V,-1V,0.2V	18V,-18,2V

Here are the Stepping Settings.

Stepping							
1:RF.Value	2:A1.LEVEL	3:	4:	5:	6:	7:	8:
Step What	RF						
List	0, 9K, 99K, 999K						
To							
Step Value							
Step It	<input checked="" type="radio"/> Yes <input type="radio"/> No		Method		Parameter Type		
			<input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List		<input checked="" type="radio"/> Component		

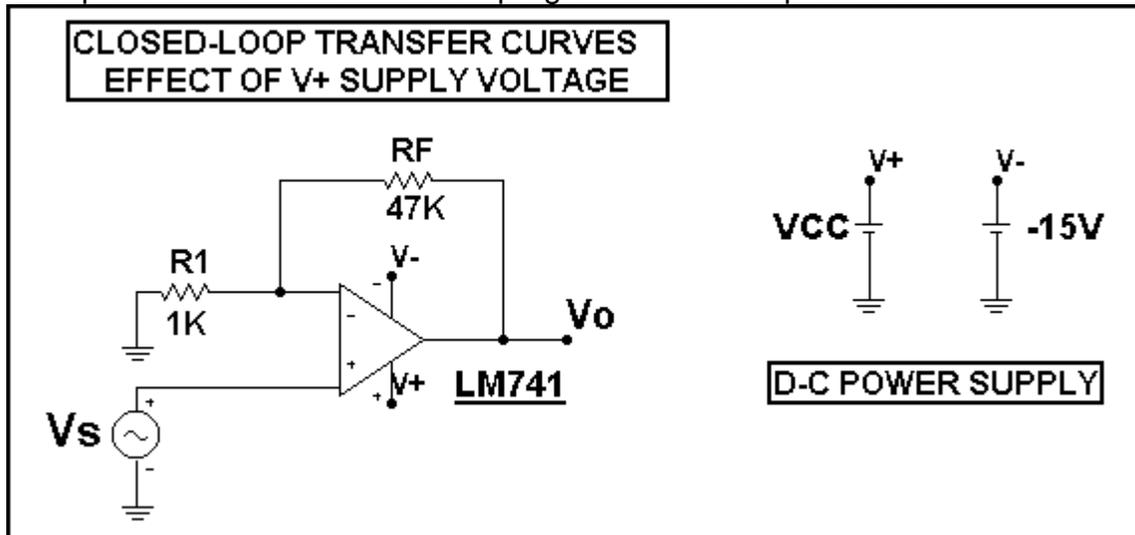
Run the Analysis.



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  $A_{CL} = 1 + (R_F/R_1)$ .

**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.

**DC Analysis Limits**

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

Temperature Method:

Temperature Range:

Number of Points:

Maximum Change %:

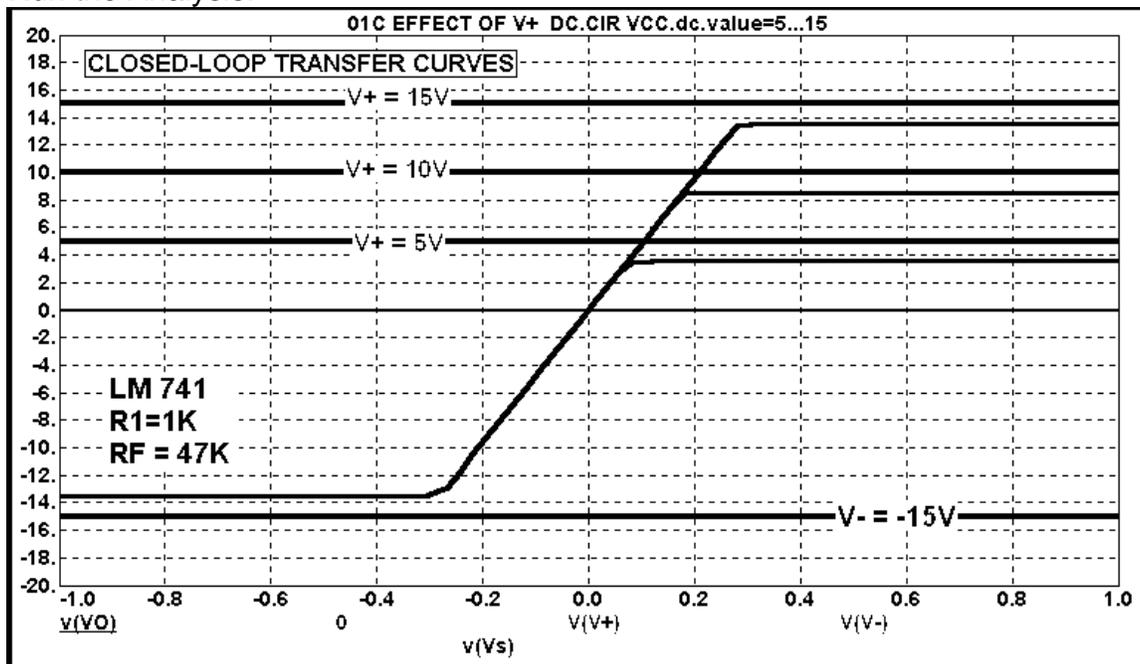
Run Options:   Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	v(Vs)	v(VO)	1V,-1V,0.2V	20V,-20V,2V
1	v(Vs)	0	1V,-1V,0.2V	20V,-20V,2V
1	v(Vs)	V(V+)	1V,-1V,0.2V	20V,-20V,2V
1	v(Vs)	V(V-)	1V,-1V,0.2V	20V,-20V,2V

Here are the Stepping Settings.

Stepping									
1:VCC.dc.value	2:	3:	4:	5:	6:	7:	8:	9:	10:
Step What	VCC								dc.value
From	5								
To	15								
Step Value	5								
Step It	Method			Parameter Type					
<input checked="" type="radio"/> Yes <input type="radio"/> No	<input checked="" type="radio"/> Linear <input type="radio"/> Log <input type="radio"/> List			<input checked="" type="radio"/> Component <input type="radio"/> Model					

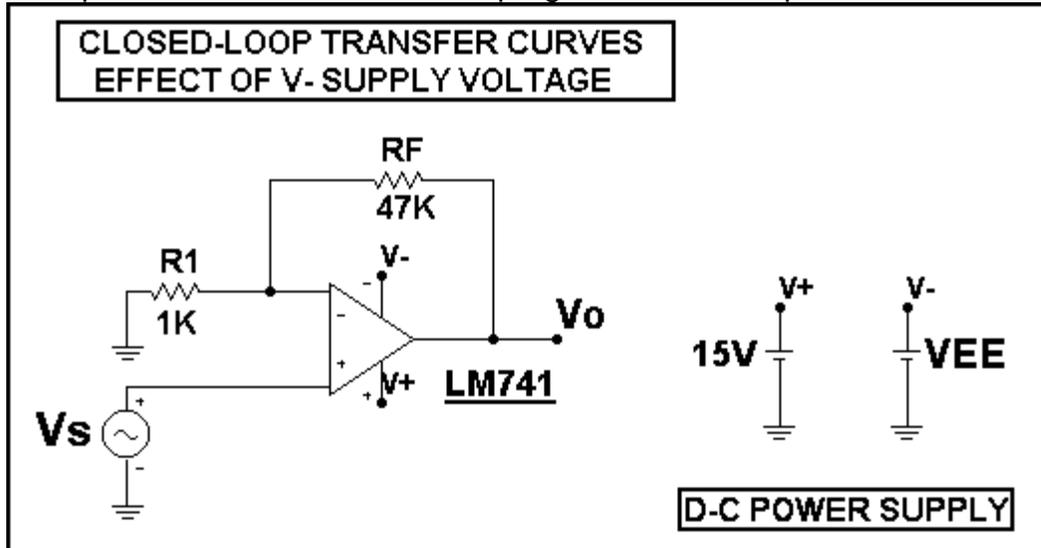
Run the Analysis.



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

**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.

**DC Analysis Limits**

Run Add Delete Expand... Stepping... Properties... Help...

Sweep

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

Temperature

Method: Linear Range: 27

Number of Points: 51

Maximum Change %: 3

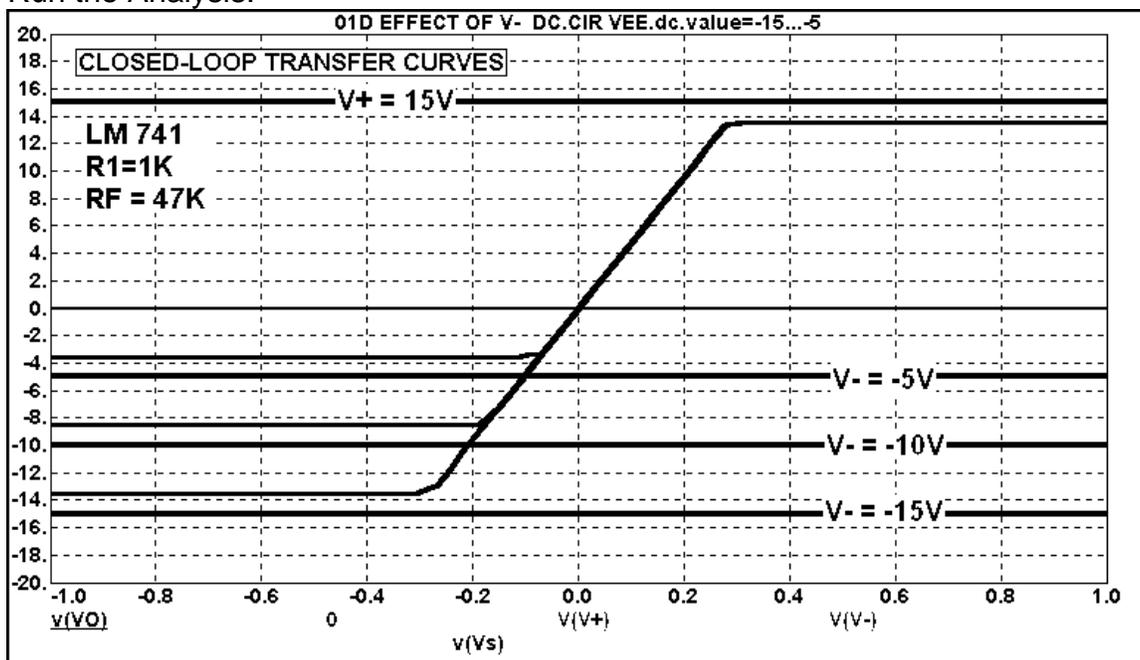
Run Options: Normal  Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	v(Vs)	v(VO)	1V,-1V,0.2V	20V,-20V,2V
1	v(Vs)	0	1V,-1V,0.2V	20V,-20V,2V
1	v(Vs)	V(V+)	1V,-1V,0.2V	20V,-20V,2V
1	v(Vs)	V(V-)	1V,-1V,0.2V	20V,-20V,2V

Here are the Stepping Settings.

Stepping									
1: VEE.dc.value	2:	3:	4:	5:	6:	7:	8:	9:	10:
Step What	VEE								dc.value
From	-5								
To	-15								
Step Value	-5								
Step It		Method			Parameter Type				
<input checked="" type="radio"/> Yes	<input type="radio"/> No	<input checked="" type="radio"/> Linear	<input type="radio"/> Log	<input type="radio"/> List	<input checked="" type="radio"/> Component	<input type="radio"/> Model			

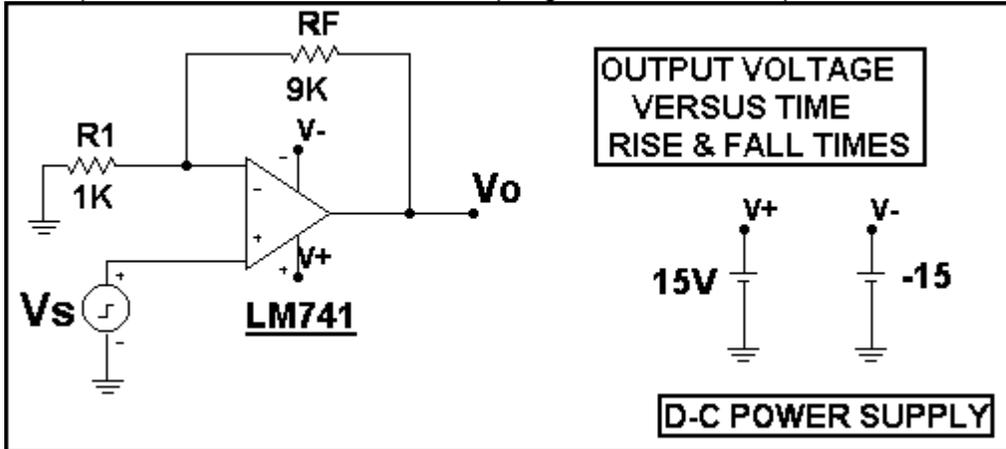
Run the Analysis.



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

**Exp 4.5 OUTPUT VOLTAGE VERSUS TIME RISE & FALL TIMES**

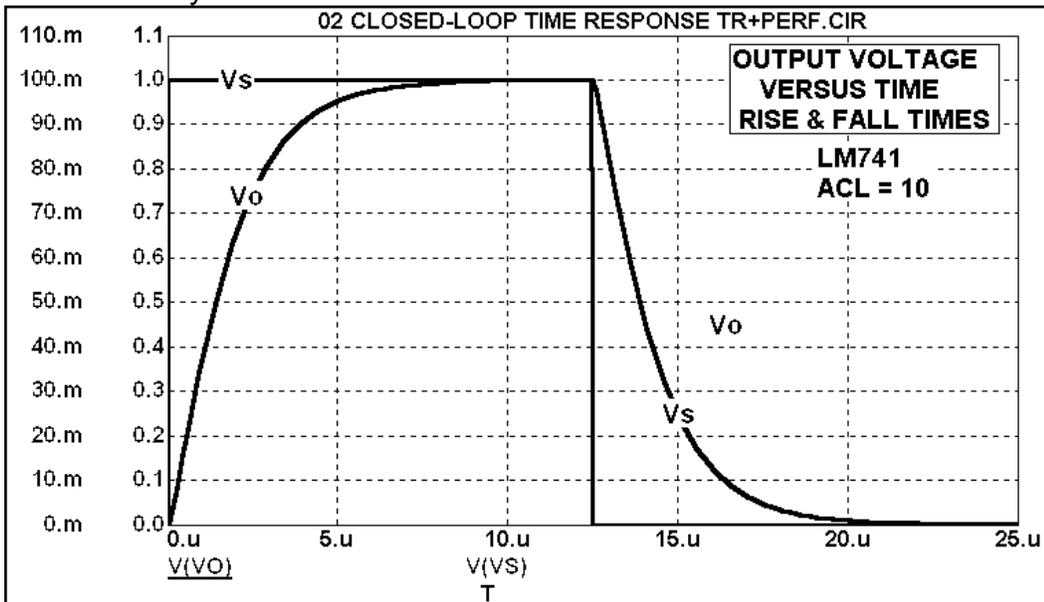
Set up this circuit in the simulation program and on the proto-board.



Use these Transient Analysis Limits.

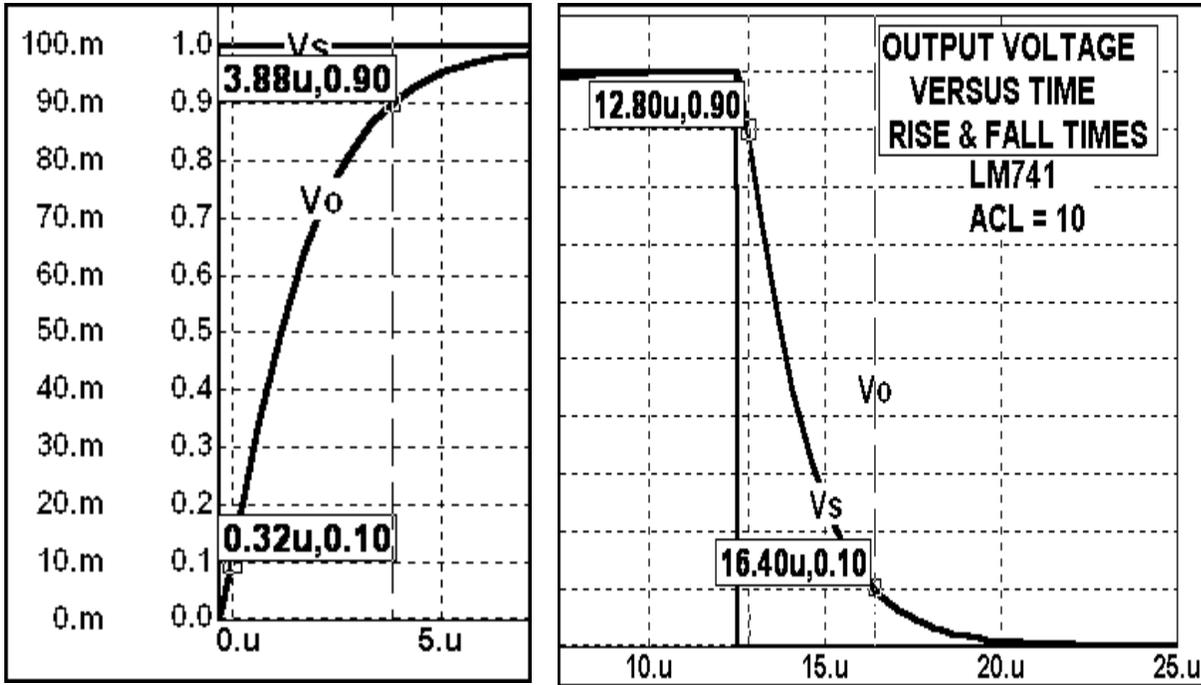
Transient Analysis Limits					
Run	Add	Delete	Expand...	Stepping...	Properties... Help...
Time Range	25us	Run Options	Normal		
Maximum Time Step	0	State Variables	Zero		
Number of Points	51	<input checked="" type="checkbox"/> Operating Point			
Temperature	Linear 27	<input type="checkbox"/> Operating Point Only			
		<input type="checkbox"/> Auto Scale Ranges			
P	X Expression	Y Expression	X Range	Y Range	
1	T	V(VO)	TMAX,TMIN	1.1V,0,0.1V	
1	T	V(VS)	TMAX,TMIN	0.11V,0,0.01V	

Run the Analysis.



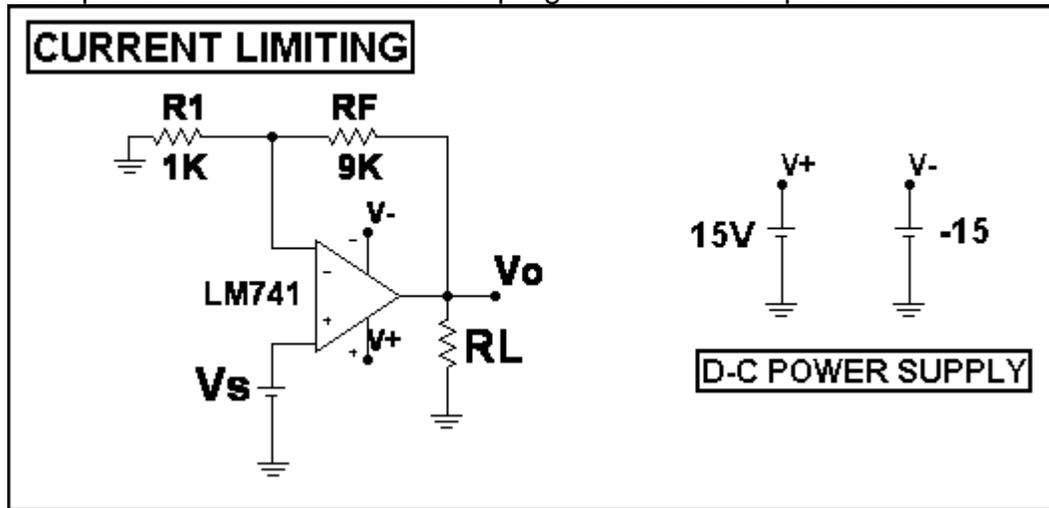
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

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

Temperature Method	Range	Number of Points	Maximum Change %
Linear	27	51	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: | 10:

Step What: **RL** Value

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

I<sub>o</sub>: \_\_\_\_\_

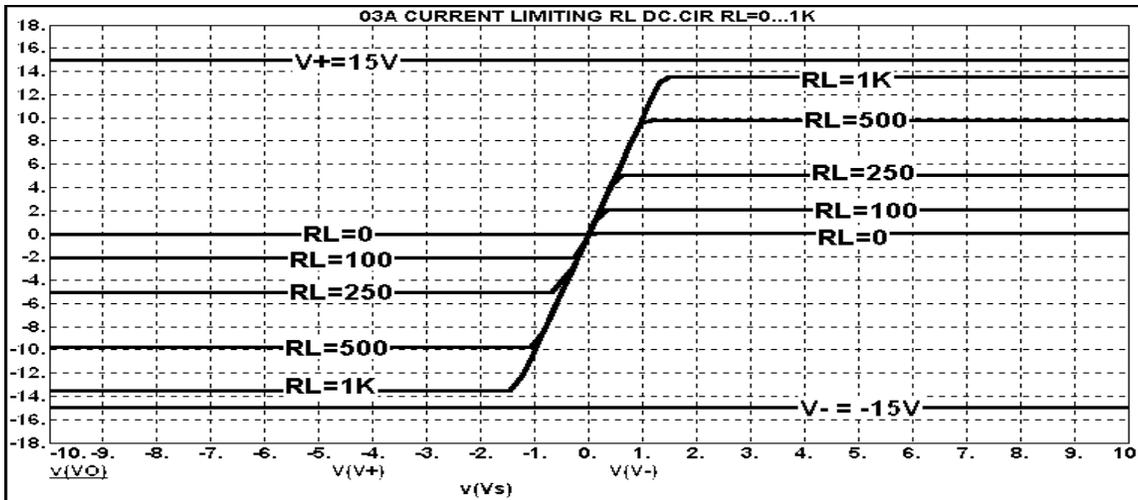
Step Value: \_\_\_\_\_

Step It:  Yes  No

Method:  Linear  Log  List

Parameter Type:  Component  Model

Run the Analysis.



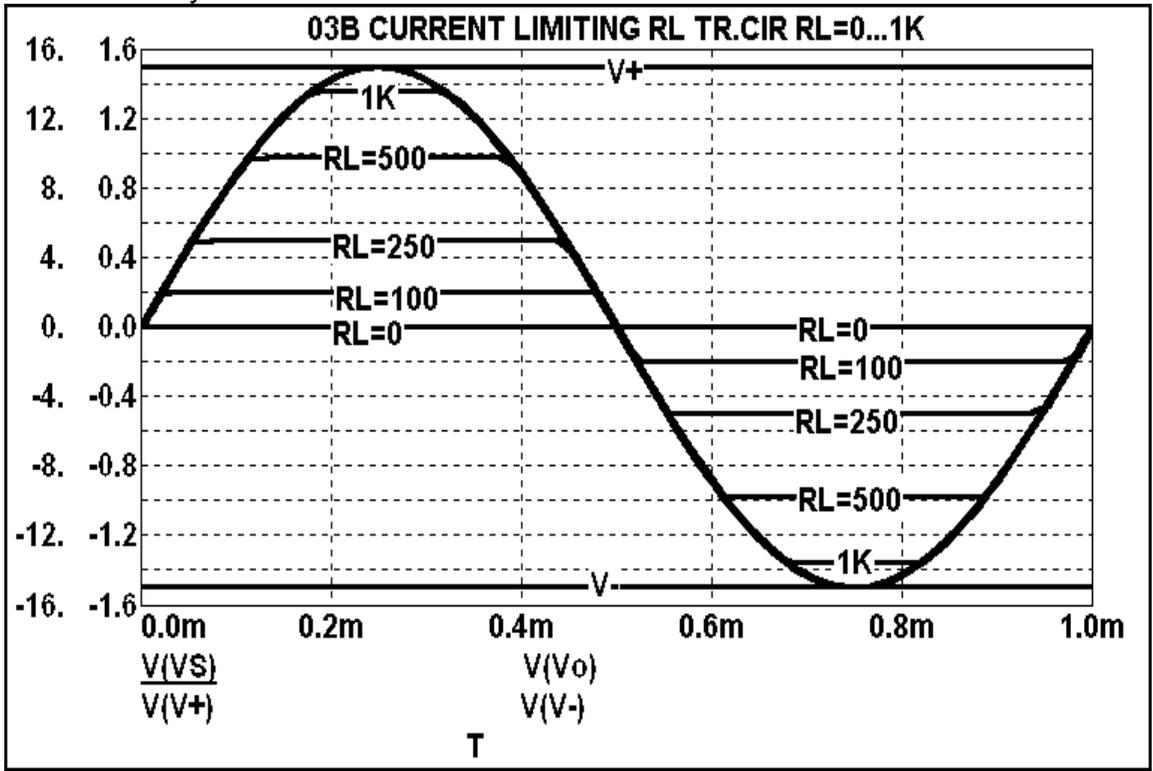
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation. The current limit of this operational amplifier is  $I_{CL} = \pm 20 \text{ mA}$ . Compare the results with the expected values.

Use these Transient Analysis Limits.

Run	Add	Delete	Expand...	Stepping...	Properties...	Help...
Time Range	1ms			Run Options	Normal	
Maximum Time Step	0			State Variables	Zero	
Number of Points	51			<input checked="" type="checkbox"/> Operating Point		
Temperature	Linear	27		<input type="checkbox"/> Operating Point Only		
		<input type="checkbox"/> Auto Scale Ranges				
	P	X Expression	Y Expression	X Range	Y Range	
	1	V(Vs)		TMAX,TMIN	1.6,-1.6,0.2	
	1	V(Vo)		TMAX,TMIN	16,-16,2	
	1	V(V+)		TMAX,TMIN	16,-16,2	
	1	V(V-)		TMAX,TMIN	16,-16,2	

Use the same Stepping Settings as before.

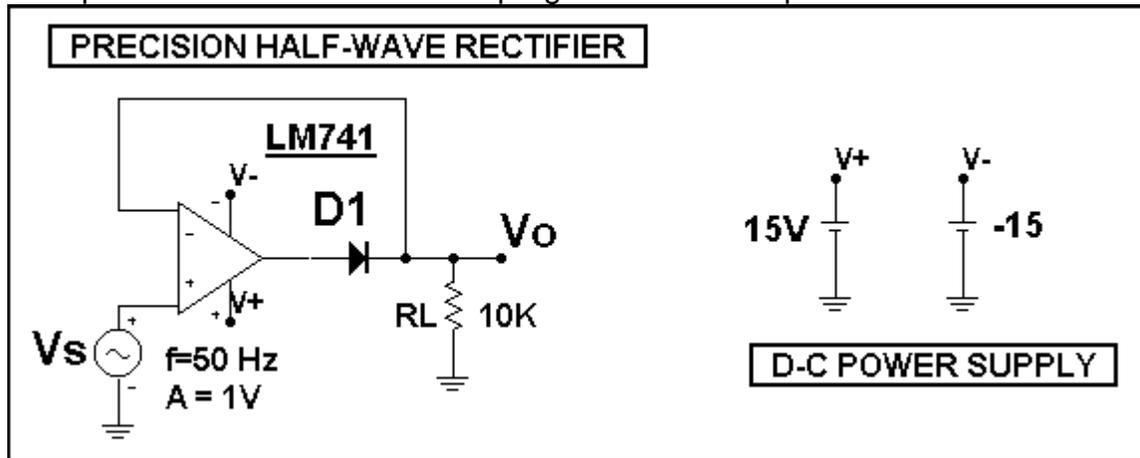
Run the Analysis.



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  $I_{CL} = \pm 20$  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.

**Transient Analysis Limits**

Run    Add    Delete    Expand...    Stepping...    Properties...    Help...

Time Range: 40ms    Run Options: Normal

Maximum Time Step: 40us    State Variables: Zero

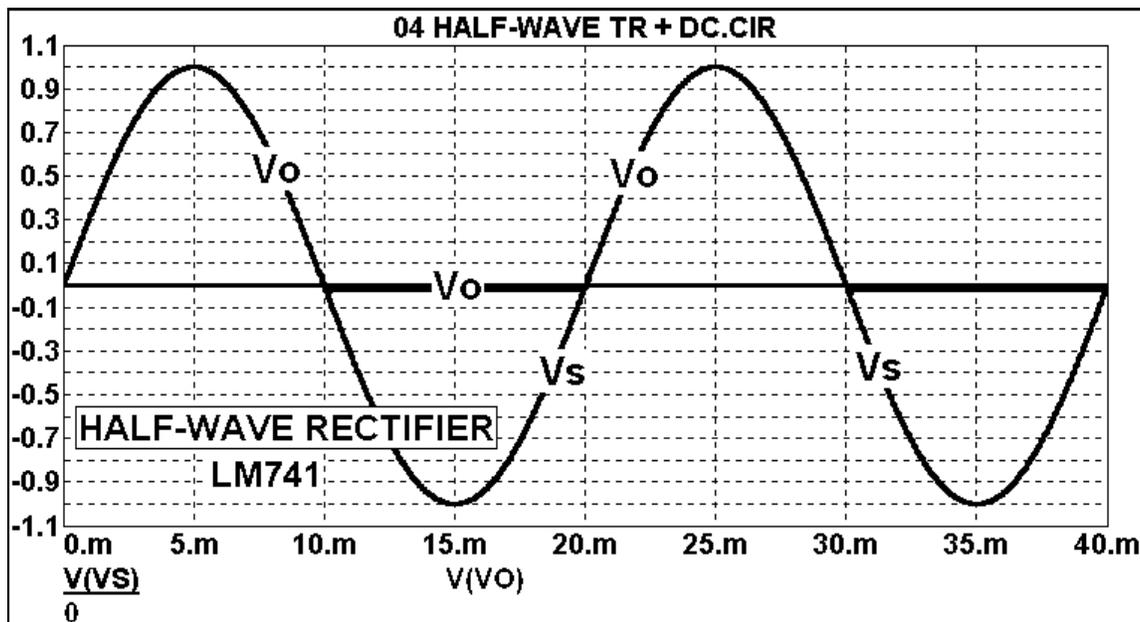
Number of Points: 51     Operating Point

Temperature: Linear    27     Operating Point Only

Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	V(VS)	V(VS)	TMAX,TMIN,5	1.1,-1.1,0.1
1	V(VO)	V(VO)	TMAX,TMIN	1.1,-1.1,0.1
1	0	0	TMAX,TMIN	1.1,-1.1,0.1

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**.

**DC Analysis Limits**

Run   Add   Delete   Expand...   Stepping...   Properties...   Help...

Sweep

Variable	Method	Name	Range
Variable 1	Auto	$V_s$	1V,-1V
Variable 2	None	NONE	NONE

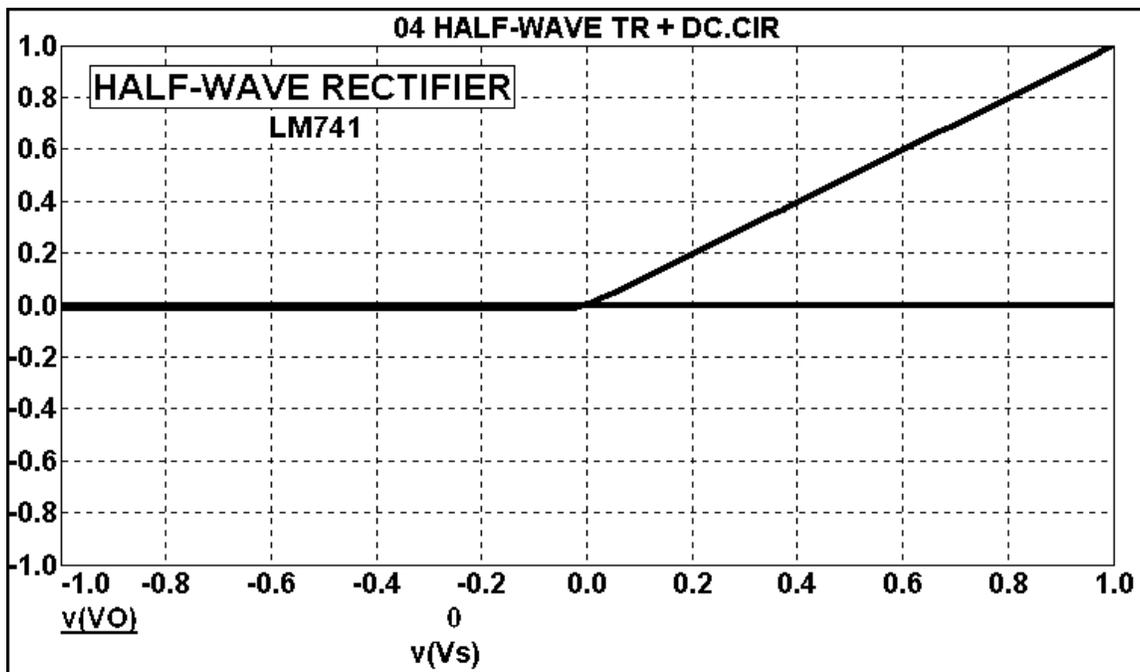
Temperature

Method	Range	Number of Points	Maximum Change %
Linear	27	51	5

Run Options: Normal    Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	$v(V_s)$	$v(V_O)$	1V,-1V,0.2	1V,-1V,0.2V
1	$v(V_s)$	0	1V,-1V,0.2	1V,-1V,0.2V

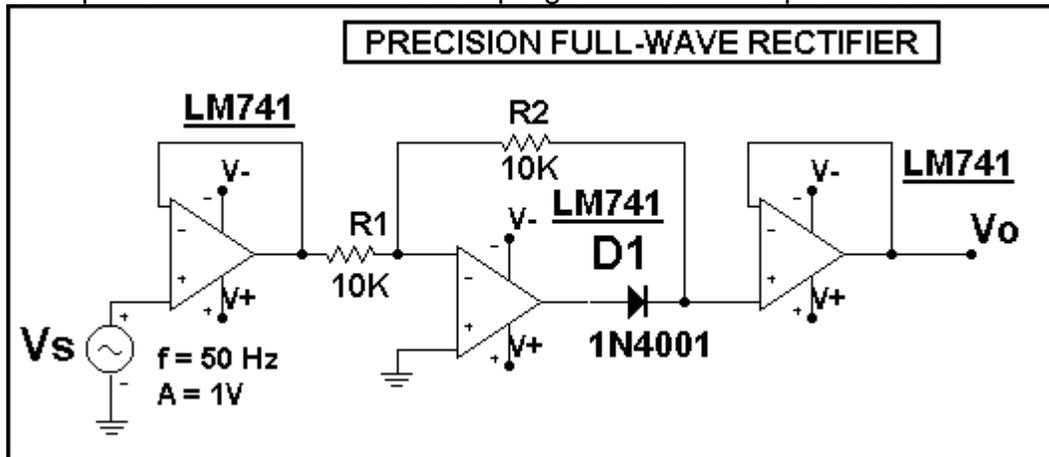
Run the Analysis.



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.

**Transient Analysis Limits**

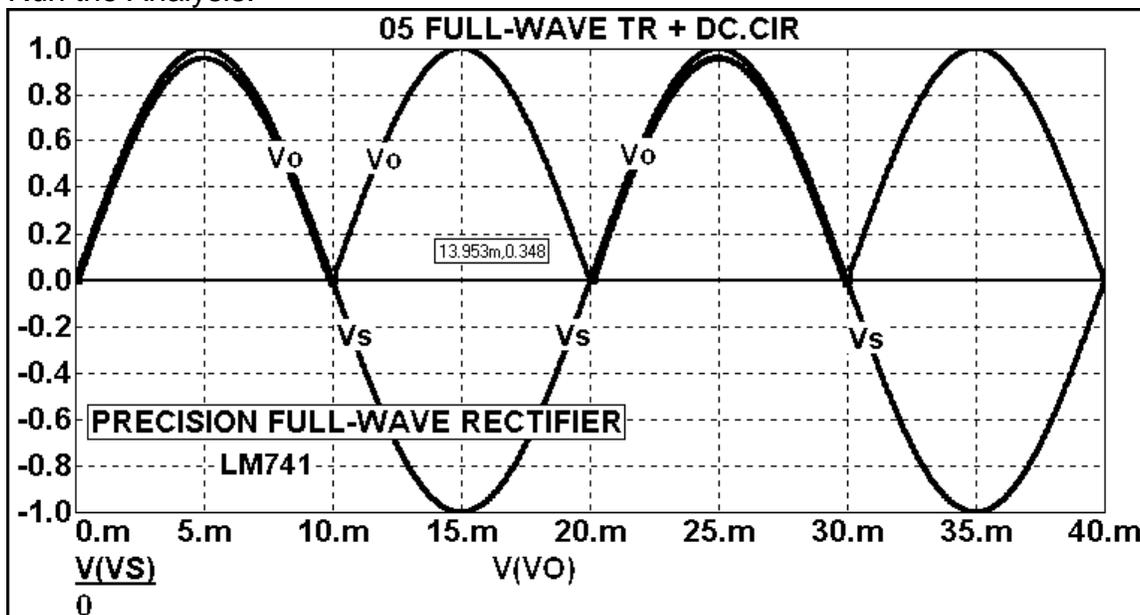
Run | Add | Delete | Expand... | Stepping... | Properties... | Help...

Time Range: 40ms  
 Maximum Time Step: 40us  
 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	V(VS)	V(VS)	TMAX,TMIN,5	1,-1,0.2
1	V(VO)	V(VO)	TMAX,TMIN,5	1,-1,0.2
1	0	0	TMAX,TMIN,5	1,-1,0.2

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**.

**DC Analysis Limits**

Run Add Delete Expand... Stepping... Properties... Help...

Sweep

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

Temperature

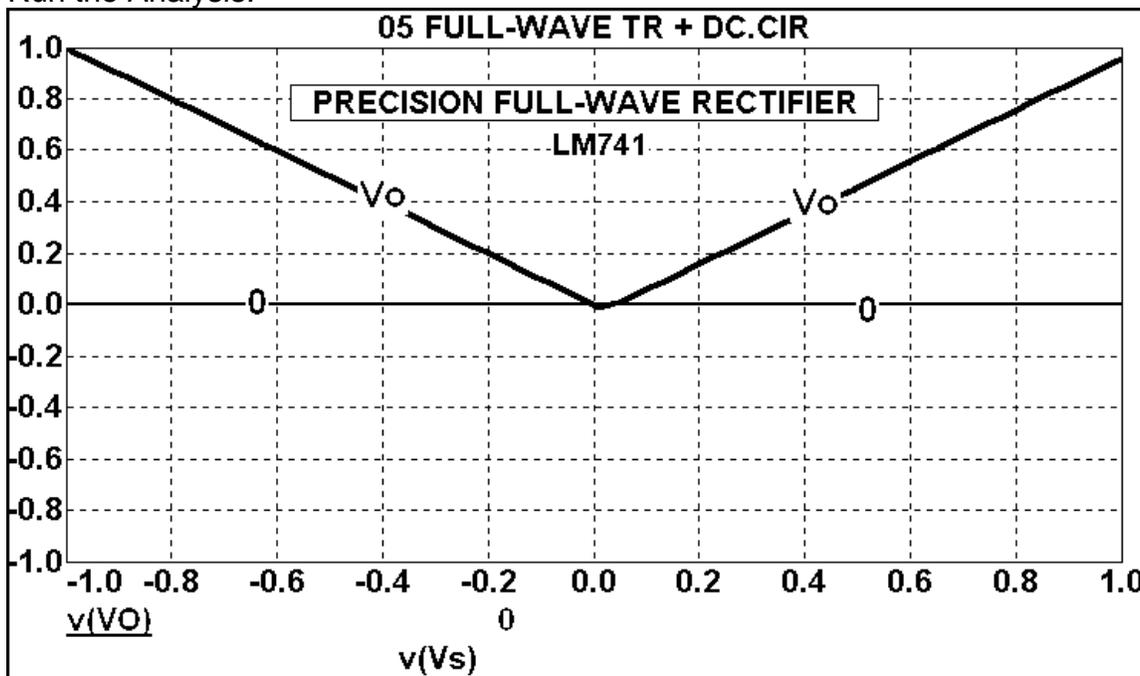
Method	Range
Linear	27

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)	1V,-1V,0.2V	1V,-1V,0.2V
1	v(Vs)	0	1V,-1V,0.2V	1V,-1V,0.2V

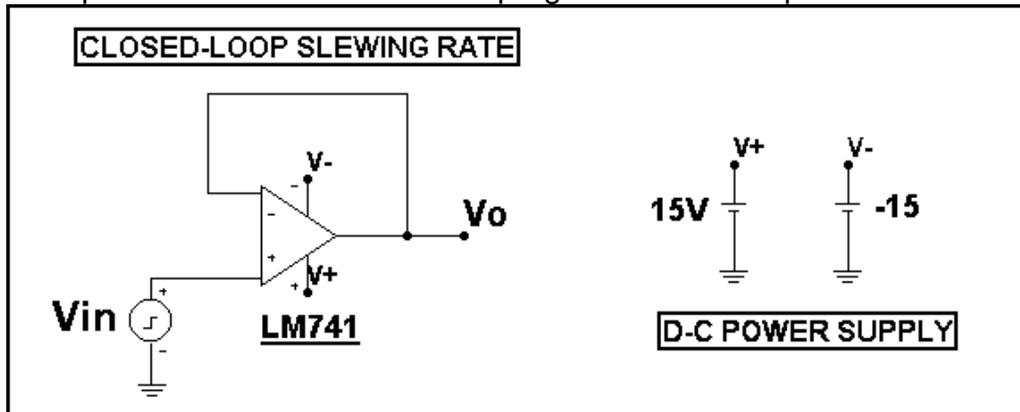
Run the Analysis.



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**

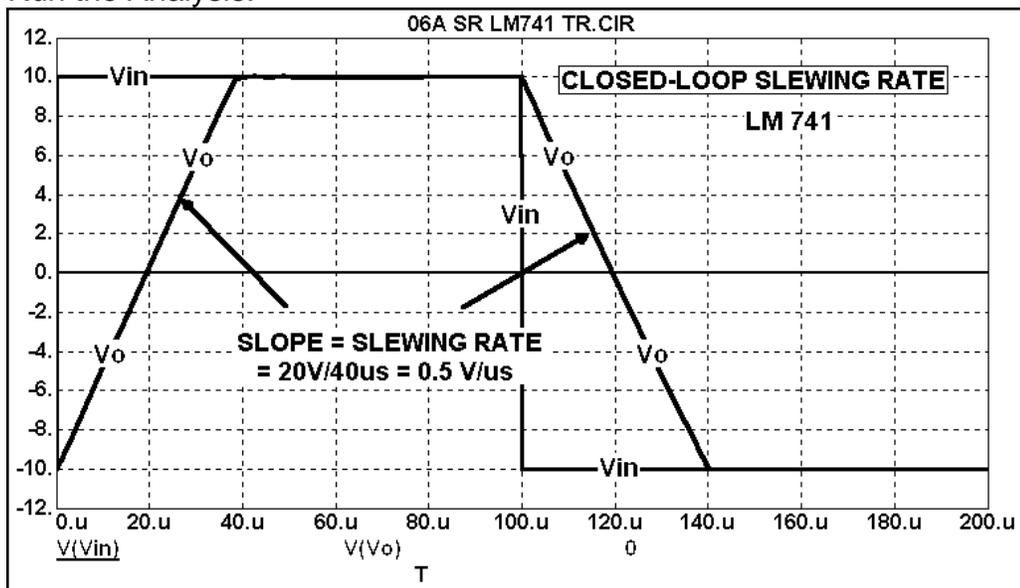
Set up this circuit in the simulation program and on the proto-board.



Use these **Transient Analysis Limits**.

Transient Analysis Limits					
Run	Add	Delete	Expand...	Stepping...	Properties... Help...
Time Range	200u	Run Options	Normal		
Maximum Time Step	0	State Variables	Zero		
Number of Points	51	<input checked="" type="checkbox"/> Operating Point			
Temperature	Linear 27	<input type="checkbox"/> Operating Point Only			
		<input type="checkbox"/> Auto Scale Ranges			
P	X Expression	Y Expression	X Range	Y Range	
1	T	V(Vin)	TMAX,TMIN,20	12V,-12V,2V	
1	T	V(Vo)	TMAX,TMIN,20	12V,-12V,2V	
1	T	0	TMAX,TMIN,20	12V,-12V,2V	

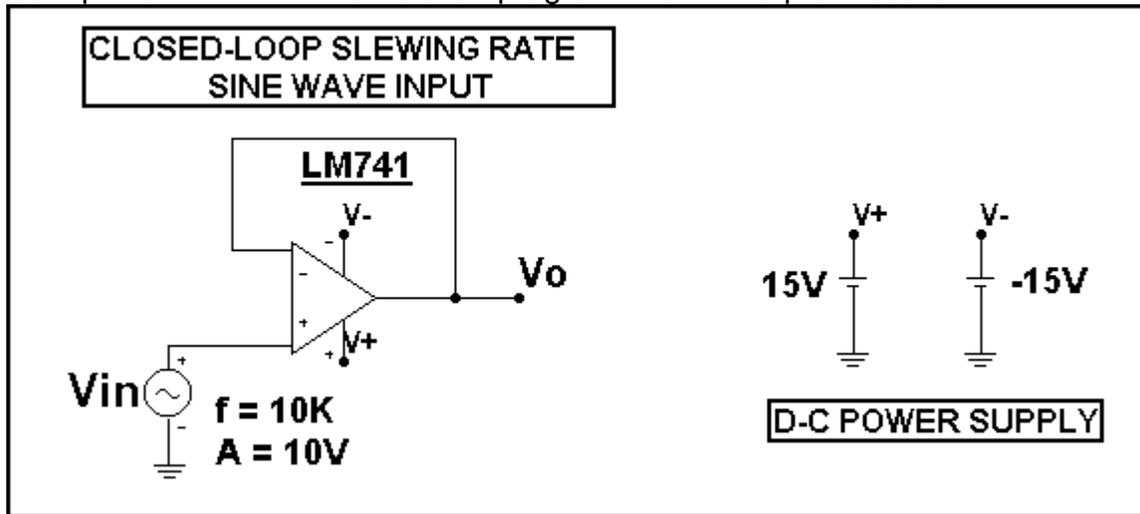
Run the Analysis.



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.



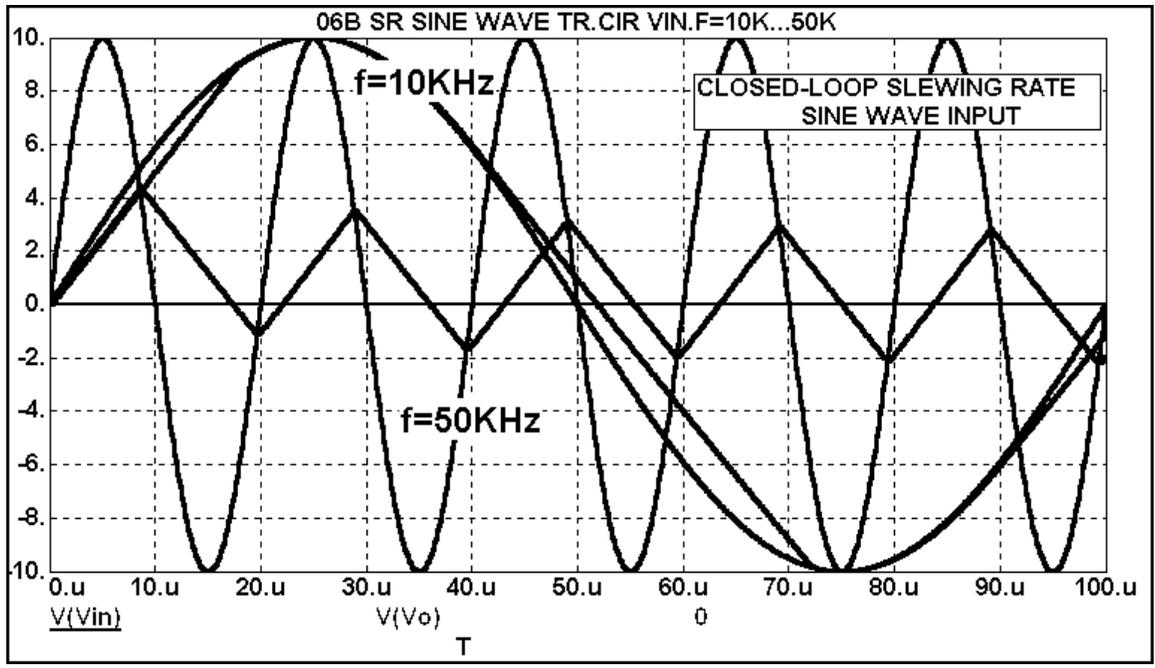
Use these **Transient Analysis Limits**.

Transient Analysis Limits					
Run	Add	Delete	Expand...	Stepping...	Properties... Help...
Time Range	100U	Run Options	Normal		
Maximum Time Step	100n	State Variables	Zero		
Number of Points	51	<input checked="" type="checkbox"/> Operating Point			
Temperature	Linear	<input type="checkbox"/> Operating Point Only			
	27	<input type="checkbox"/> Auto Scale Ranges			
P	X Expression	Y Expression	X Range	Y Range	
1	T	V(Vin)	TMAX,TMIN,10	10,-10,2	
1	T	V(Vo)	TMAX,TMIN,10	10,-10,2	
1	T	0	TMAX,TMIN,10	10,-10,2	

Here are the **Stepping Settings**.

Stepping									
1:VIN.F	2:A1.LEVEL	3:	4:	5:	6:	7:	8:	9:	10:
Step What	VIN								
List	10K,50K								
To	80K								
Step Value	2								
Step It	<input checked="" type="radio"/> Yes <input type="radio"/> No			Method <input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List			Parameter Type <input checked="" type="radio"/> Component <input type="radio"/> Model		

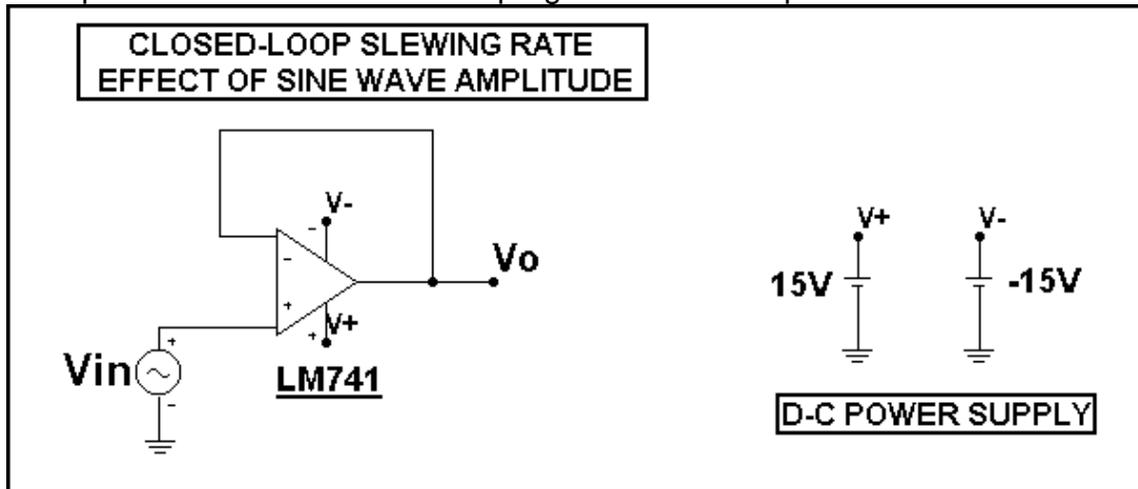
Run the Analysis.



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

**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.



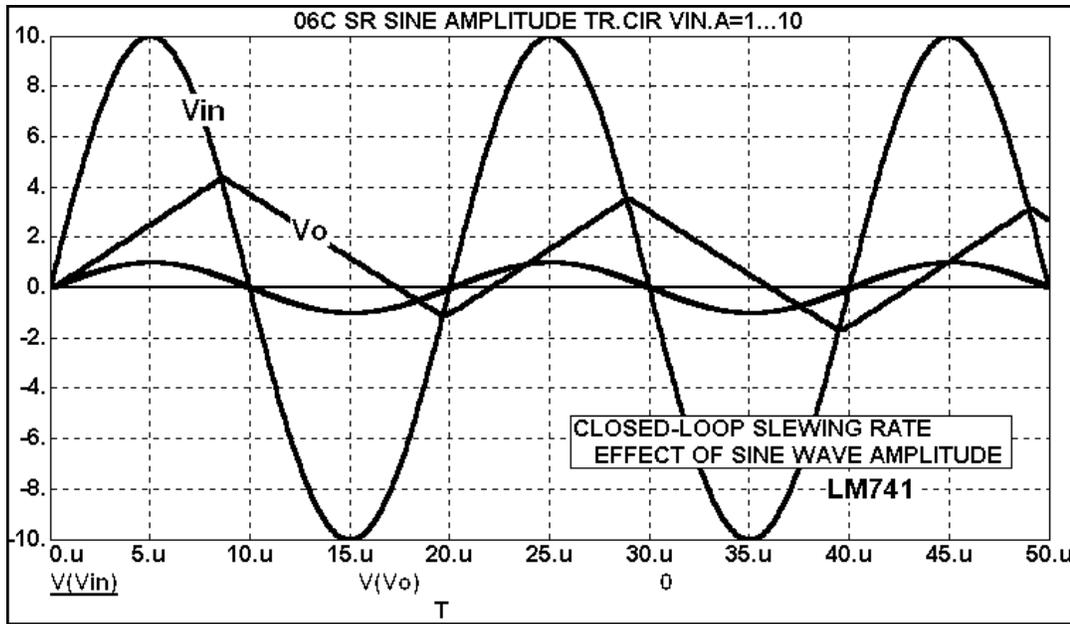
Use these **Transient Analysis Limits**.

Run	Add	Delete	Expand...	Stepping...	Properties...	Help...
Time Range	50us			Run Options	Normal	
Maximum Time Step	100n			State Variables	Zero	
Number of Points	51			<input checked="" type="checkbox"/> Operating Point		
Temperature	Linear	27		<input type="checkbox"/> Operating Point Only		
				<input type="checkbox"/> Auto Scale Ranges		
	P	X Expression	Y Expression	X Range	Y Range	
	1	T	V(Vin)	TMAX,TMIN,5u	10V,-10V,2V	
	1	T	V(Vo)	TMAX,TMIN,5u	10V,-10V,2V	
	1	T	0	TMAX,TMIN,5u	10V,-10V,2V	

Here are the **Stepping Settings**.

1:VIN.A	2:A1.LEVEL	3:	4:	5:	6:	7:	8:	9:
Step What	VIN A							
List	1,10							
Io	80K							
Step Value	2							
Step It	<input checked="" type="radio"/> Yes <input type="radio"/> No		Method			Parameter Type		
			<input type="radio"/> Linear <input type="radio"/> Log <input checked="" type="radio"/> List			<input checked="" type="radio"/> Component		

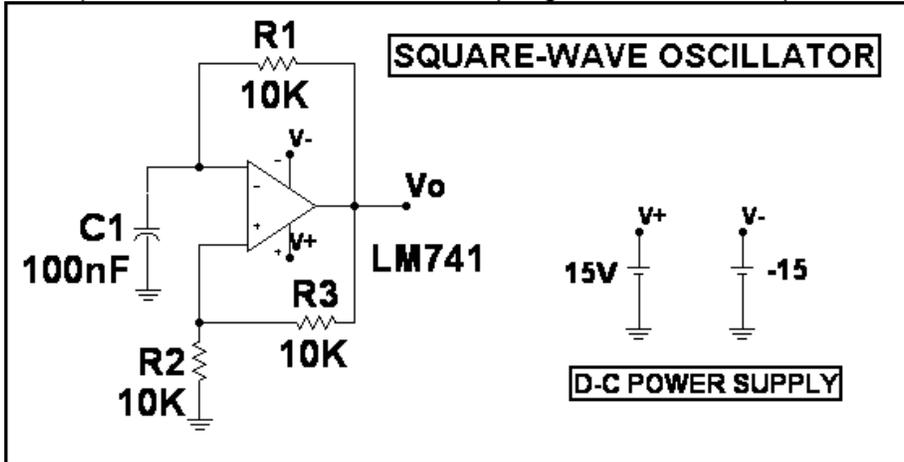
Run the Analysis.



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.

**Transient Analysis Limits**

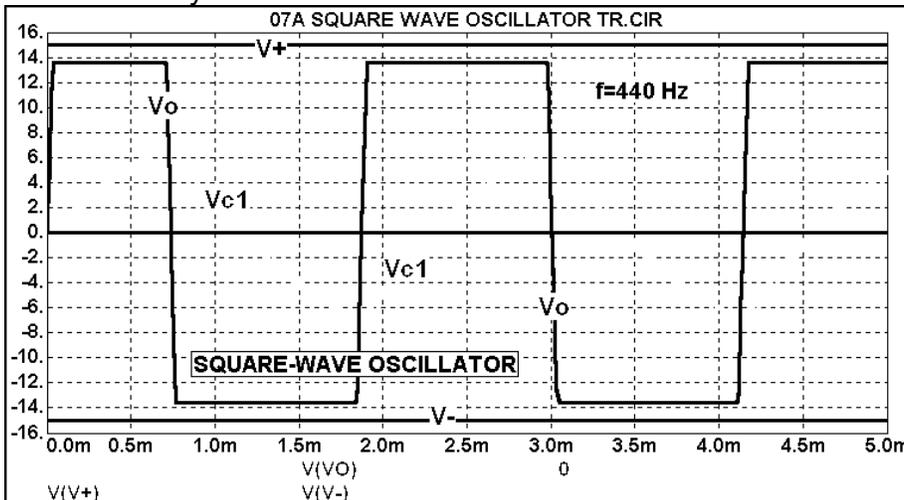
Run | Add | Delete | Expand... | Stepping... | Properties... | Help...

Time Range: 5ms | Run Options: Normal  
 Maximum Time Step: 0 | State Variables: Zero  
 Number of Points: 51  
 Temperature: Linear | 27

Operating Point  
 Operating Point Only  
 Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	V(C1)	V(C1)	TMAX,TMIN,50	16,-16,2
1	V(V0)	V(V0)	TMAX,TMIN	16,-16,2
1	0	0	TMAX,TMIN	16,-16,2
1	V(V+)	V(V+)	TMAX,TMIN	16,-16,2
1	V(V-)	V(V-)	TMAX,TMIN	16,-16,2

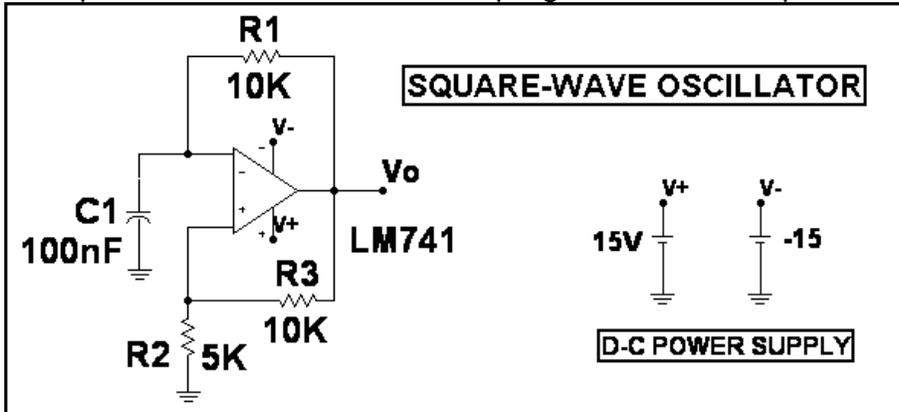
Run the Analysis.



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**.

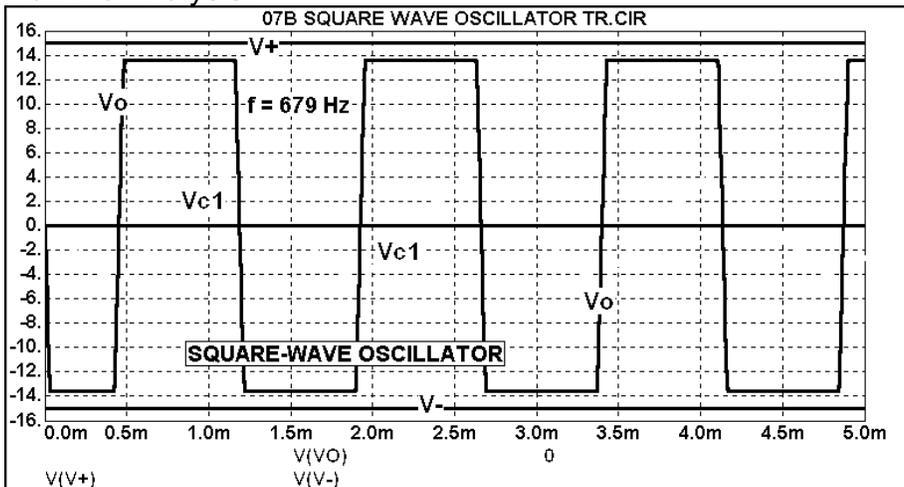
**Transient Analysis Limits**

Run | Add | Delete | Expand... | Stepping... | Properties... | Help...

Time Range: 5ms | Run Options: Normal  
 Maximum Time Step: 5us | State Variables: Zero  
 Number of Points: 51 |  Operating Point  
 Temperature: Linear | 27 |  Operating Point Only  
 Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	T	V(C1)	TMAX,TMIN,50	16,-16,2
1	T	V(V0)	TMAX,TMIN	16,-16,2
1	T	0	TMAX,TMIN	16,-16,2
1	T	V(V+)	TMAX,TMIN	16,-16,2
1	T	V(V-)	TMAX,TMIN	16,-16,2

Run the Analysis.



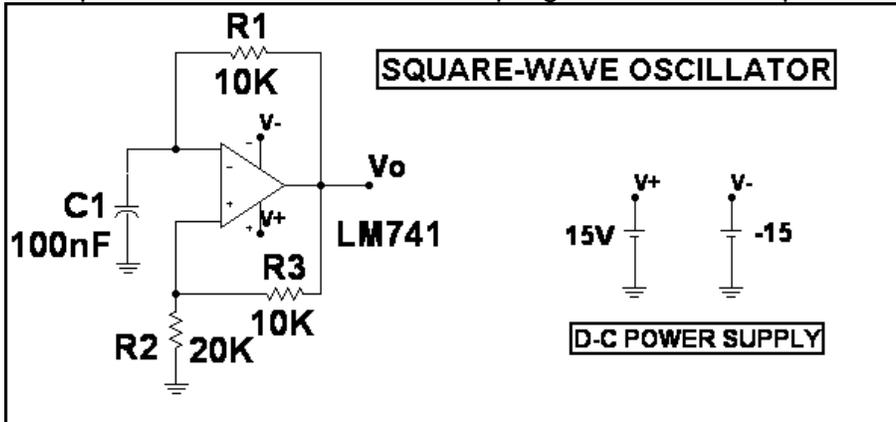
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

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**

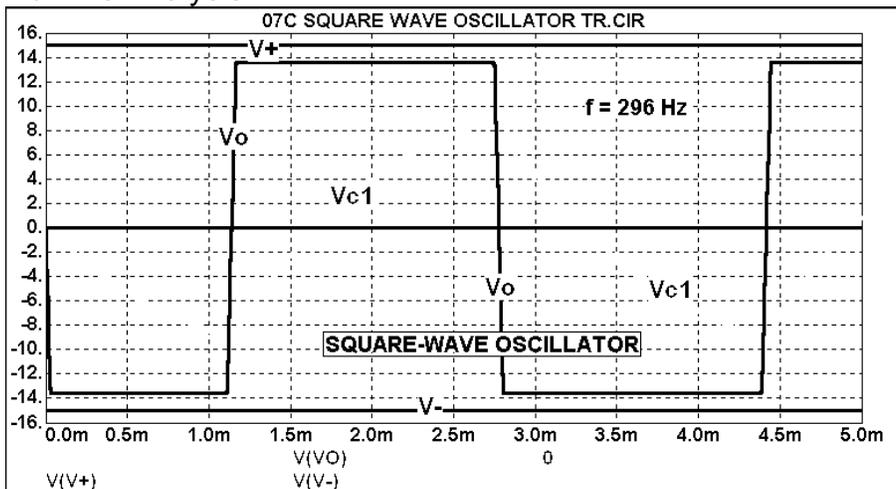
Set up this circuit in the simulation program and on the proto-board.



Use these Transient Analysis Limits.

Transient Analysis Limits					
Run	Add	Delete	Expand...	Stepping...	Properties... Help...
Time Range	5ms	Run Options	Normal		
Maximum Time Step	5us	State Variables	Zero		
Number of Points	51	<input type="checkbox"/> Operating Point			
Temperature	Linear 27	<input type="checkbox"/> Operating Point Only			
		<input type="checkbox"/> Auto Scale Ranges			
P	X Expression	Y Expression	X Range	Y Range	
T	V(C1)		TMAX,TMIN,50	16,-16,2	
T	V(V0)		TMAX,TMIN	16,-16,2	
T	0		TMAX,TMIN	16,-16,2	
T	V(V+)		TMAX,TMIN	16,-16,2	
T	V(V-)		TMAX,TMIN	16,-16,2	

Run the Analysis.



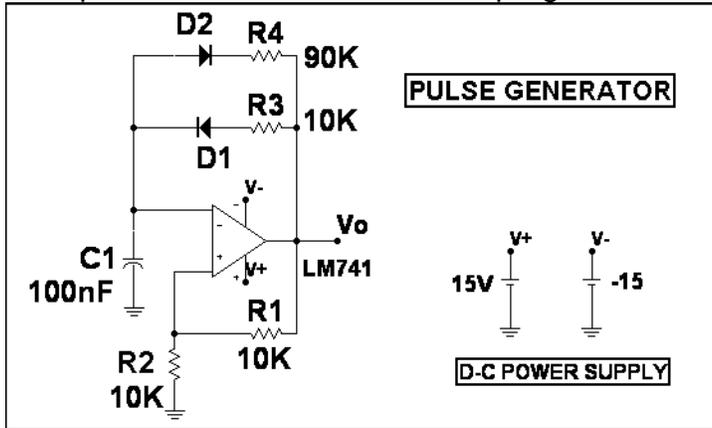
Test the circuit and observe the results on the oscilloscope. Compare the results as seen on the oscilloscope with the simulation.

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.

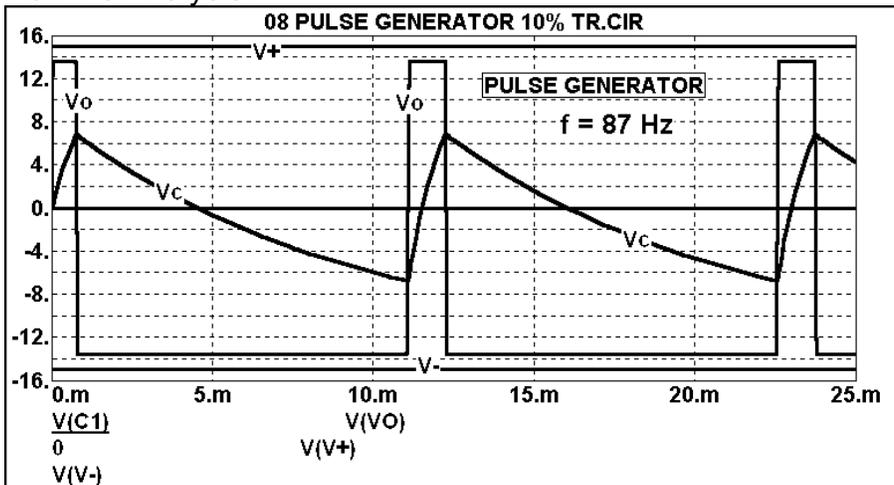
**Transient Analysis Limits**

Run Add Delete Expand... Stepping... Properties... Help...

Time Range: 25ms Run Options: Normal  
 Maximum Time Step: 0 State Variables: Zero  
 Number of Points: 51  Operating Point  
 Temperature: Linear 27  Operating Point Only  
 Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
T	T	V(C1)	TMAX,TMIN	16V,-16V,2V
T	T	V(V0)	TMAX,TMIN	16V,-16V,2V
T	T	0	TMAX,TMIN	16V,-16V,2V
T	T	V(V+)	TMAX,TMIN	16V,-16V,2V
T	T	V(V-)	TMAX,TMIN	16V,-16V,2V

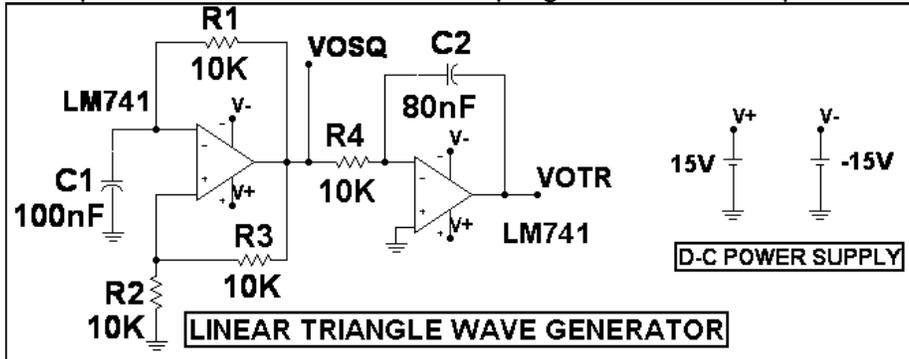
Run the Analysis.



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**

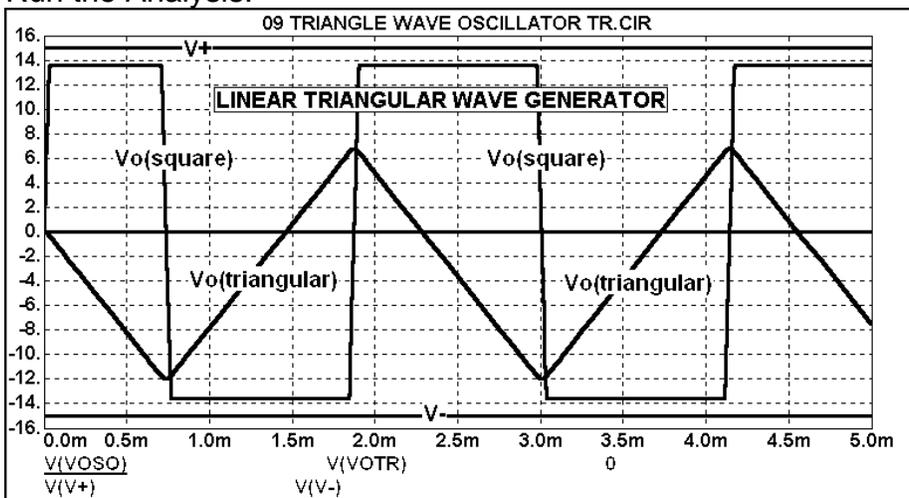
Set up this circuit in the simulation program and on the proto-board.



Use these Transient Analysis Limits.

Transient Analysis Limits					
Run		Add		Delete	
Expand...		Stepping...		Properties...	
Help...					
Time Range	5ms	Run Options	Normal		
Maximum Time Step	0	State Variables	Zero		
Number of Points	51	<input type="checkbox"/> Operating Point			
Temperature	Linear	<input type="checkbox"/> Operating Point Only			
	27	<input type="checkbox"/> Auto Scale Ranges			
P	X Expression	Y Expression	X Range	Y Range	
T	V(VOSQ)	TMAX,TMIN,0	16,-16,2		
T	V(VOTR)	TMAX,TMIN	16,-16,2		
T	0	TMAX,TMIN	16,-16,2		
T	V(V+)	TMAX,TMIN	16,-16,2		
T	V(V-)	TMAX,TMIN	16,-16,2		

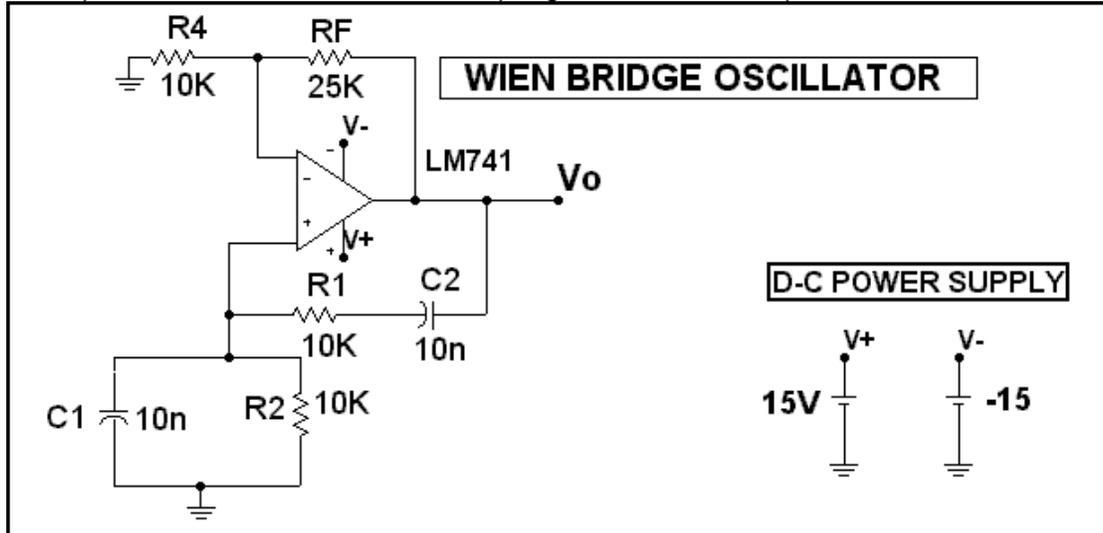
Run the Analysis.



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.

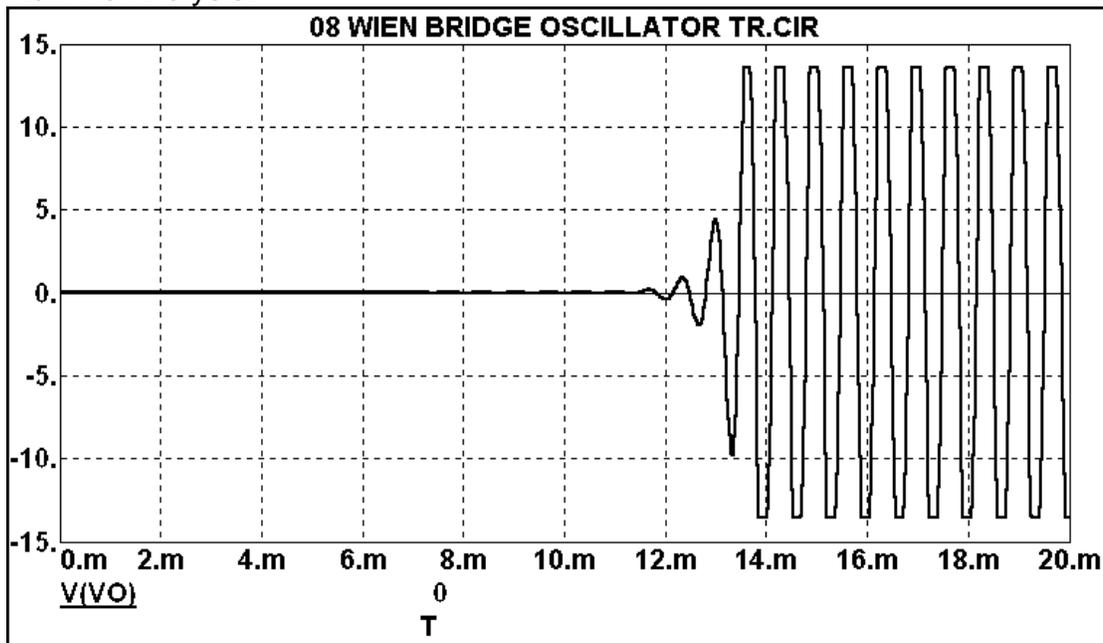


Use these Transient Analysis Limits.

Time Range	20ms	Run Options	Normal
Maximum Time Step	20us	State Variables	Zero
Number of Points	51	<input checked="" type="checkbox"/> Operating Point	
Temperature	Linear 27	<input type="checkbox"/> Operating Point Only	
		<input type="checkbox"/> Auto Scale Ranges	

P	X Expression	Y Expression	X Range	Y Range
1	V(VO)	V(VO)	MAX,TMIN,2m	15,-15,5
1	T	0	MAX,TMIN,2m	15,-15,5

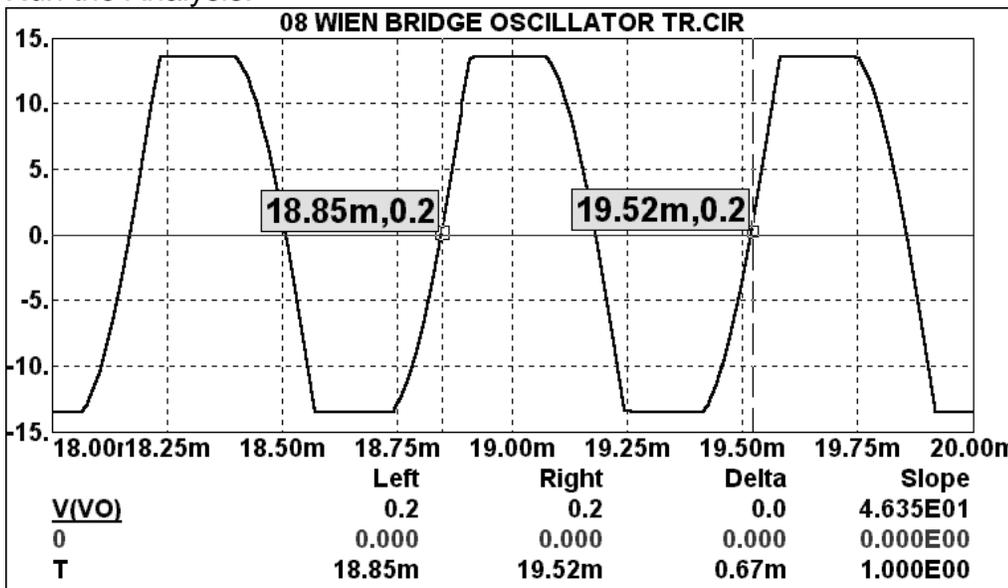
Run the Analysis.



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

Run	Add	Delete	Expand...	Stepping...	Properties...	Help...
Time Range	20ms			Run Options	Normal	
Maximum Time Step	20us			State Variables	Zero	
Number of Points	51			<input checked="" type="checkbox"/> Operating Point		
Temperature	Linear	27		<input type="checkbox"/> Operating Point Only		
				<input type="checkbox"/> Auto Scale Ranges		
	P	X Expression	Y Expression	X Range	Y Range	
	1	V(VO)		20m,18m,0.25m	15,-15,5	
	1	0		20m,18m,0.25m	15,-15,5	

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

$$f_{osc} = 1 / [ 2 \cdot \pi \cdot \sqrt{(R_1 R_2 C_1 C_2)} ]$$

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

$$f_{osc} = 1 / [ 2 \cdot \pi \cdot R_1 \cdot C_1 ]$$

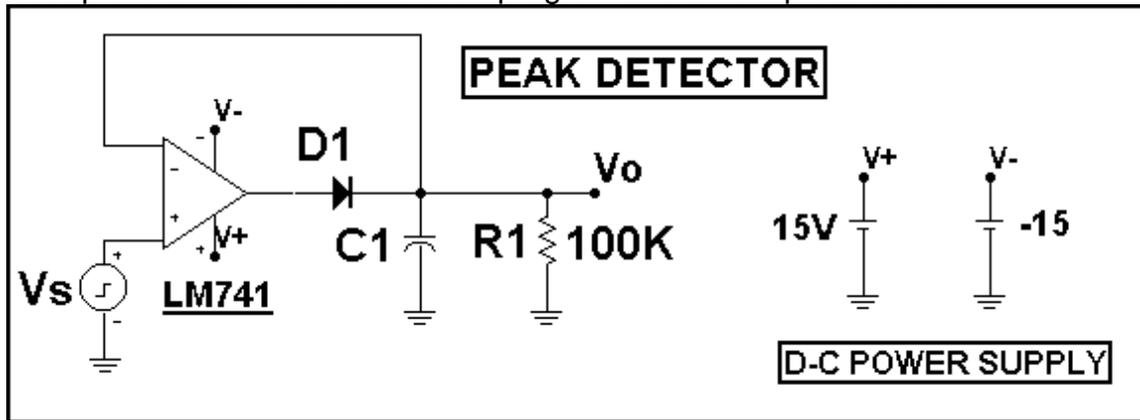
The condition for oscillations to occur is that

$$R_F / R_4 > (R_1/R_2) + (C_2/C_1)$$

For this circuit this becomes  $R_F / R_4 > 2$ , so that if  $R_4 = 10$  K $\Omega$ , then  $R_F > 20$  K $\Omega$ . 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.



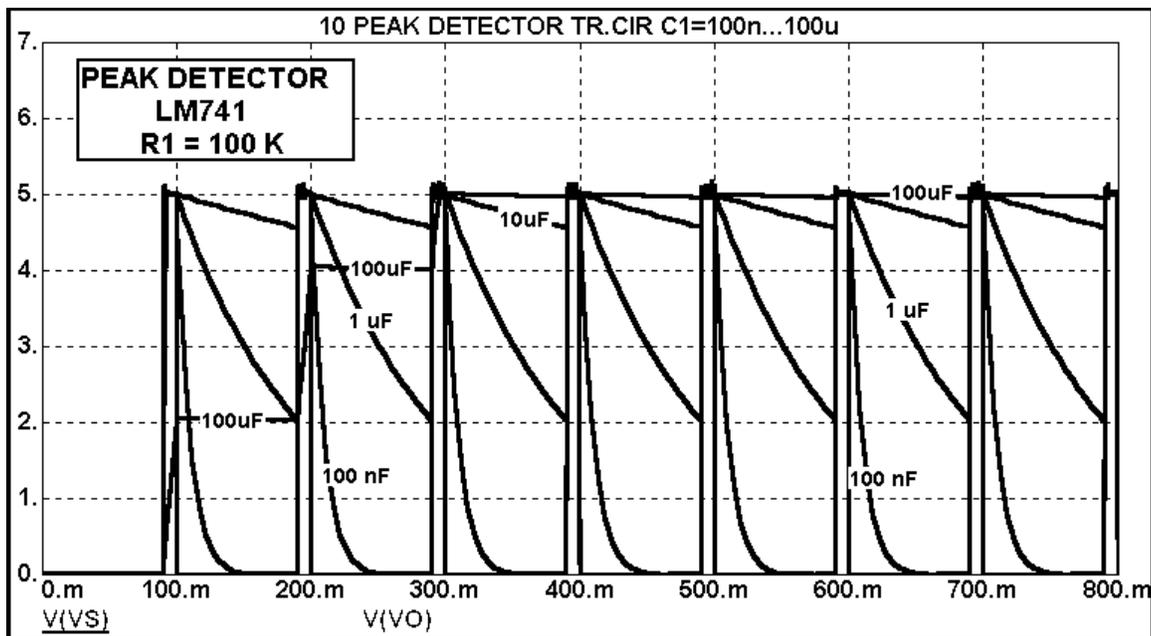
Use these **Transient Analysis Limits**.

Transient Analysis Limits					
Run	Add	Delete	Expand...	Stepping...	Properties... Help...
Time Range	800ms	Run Options	Normal		
Maximum Time Step	0.5ms	State Variables	Zero		
Number of Points	51	<input type="checkbox"/> Operating Point			
Temperature	Linear	<input type="checkbox"/> Operating Point Only			
	27	<input type="checkbox"/> Auto Scale Ranges			
P	X Expression	Y Expression	X Range	Y Range	
1	V(VS)		TMAX,TMIN	7V,0.1V	
1	V(VO)		TMAX,TMIN	7V,0.1V	

Here are the **Stepping Settings**.

Transient Analysis Limits					
Run	Add	Delete	Expand...	Stepping...	Properties... Help...
Time Range	800ms	Run Options	Normal		
Maximum Time Step	5ms	State Variables	Zero		
Number of Points	51	<input type="checkbox"/> Operating Point			
Temperature	Linear	<input type="checkbox"/> Operating Point Only			
	27	<input type="checkbox"/> Auto Scale Ranges			
P	X Expression	Y Expression	X Range	Y Range	
1	V(VS)		TMAX,TMIN,10	7V,0.1V	
1	V(VO)		TMAX,TMIN,10	7V,0.1V	

Run the Analysis.



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

**Transient Analysis Limits**

Run Add Delete Expand... Stepping... Properties... Help...

Time Range: 800ms Run Options: Normal

Maximum Time Step: 5ms State Variables: Zero

Number of Points: 51

Temperature: Linear 27

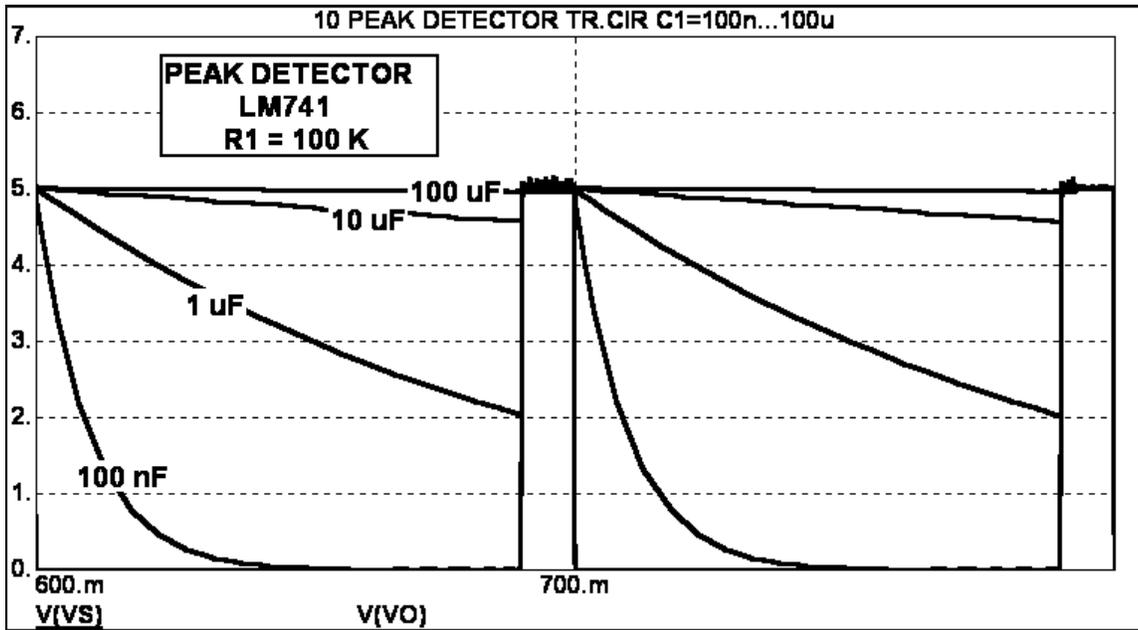
Operating Point

Operating Point Only

Auto Scale Ranges

P	X Expression	Y Expression	X Range	Y Range
1	V(VS)		800ms,600ms,1	7V,0,1V
1	V(VO)		800ms,600ms,1	7V,0,1V

Run the Analysis.



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

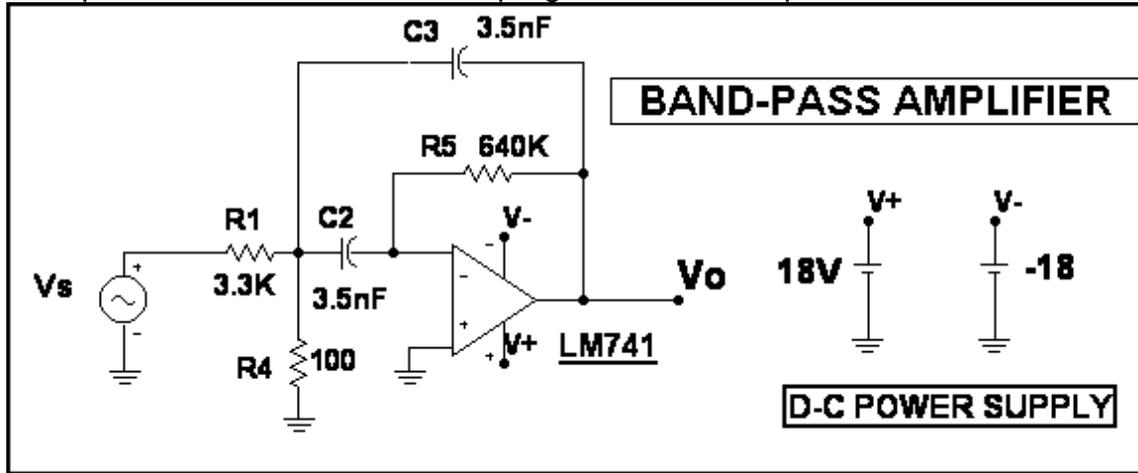
The decay of the output voltage versus time is given by

$$V_o(t) = V_s \cdot \epsilon^{-t/(R1 \cdot C1)}$$

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.



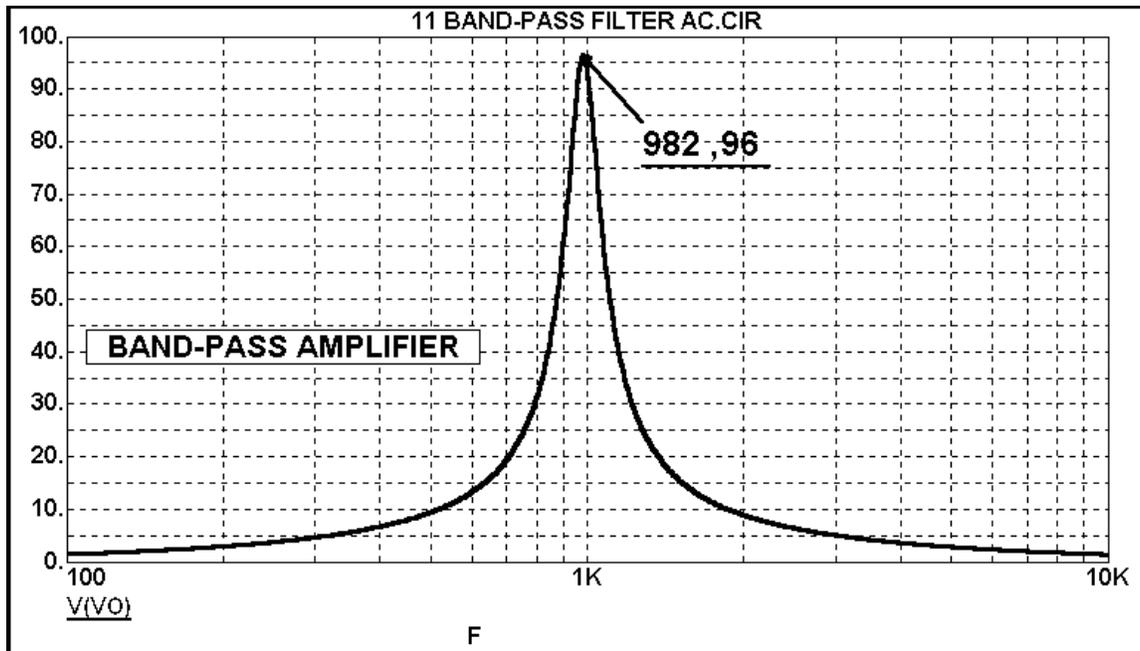
Use these A-C Analysis Limits.

Frequency Range	10K,100	Run Options	Normal
Number of Points	511	State Variables	Zero
Temperature	Linear	Frequency Step	Log
Maximum Change %	5	<input checked="" type="checkbox"/> Operating Point	
Noise Input	NONE	<input type="checkbox"/> Auto Scale Ranges	
Noise Output	2		

P	X Expression	Y Expression	X Range	Y Range
1	F	V(VO)	FMAX,FMIN	100,0,5

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

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

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

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

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

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

**Exp 4.20 Bandwidth of the Band-Pass Amplifier**

Use these A-C Analysis Limits.

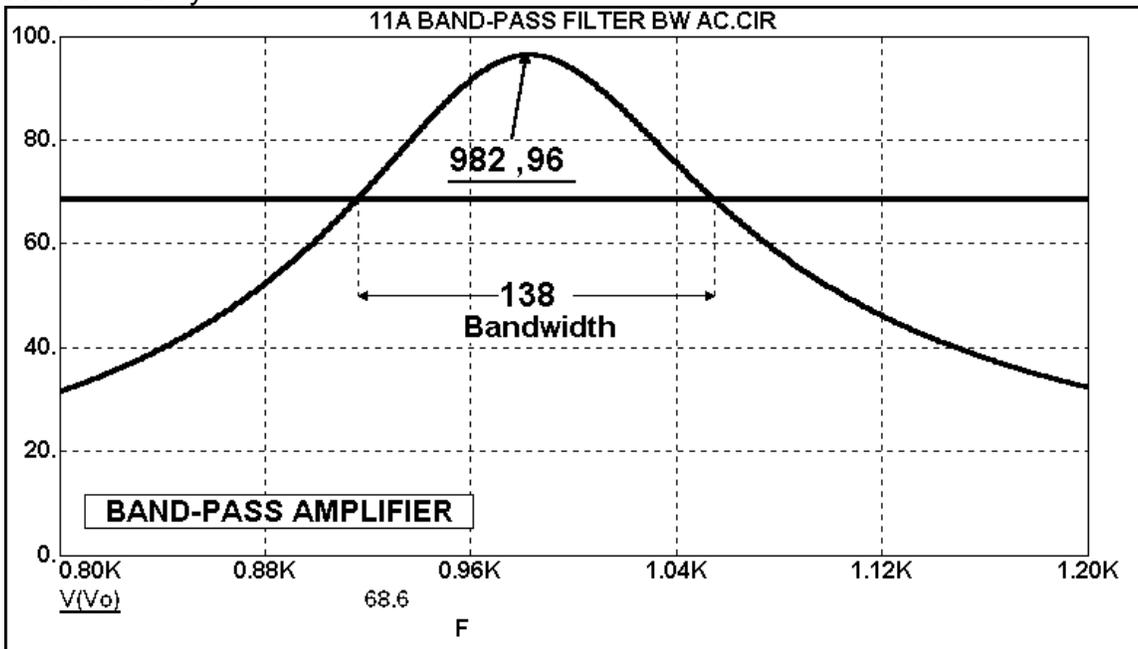
Frequency Range	1.2K,800	Run Options	Normal
Number of Points	511	State Variables	Zero
Temperature	Linear	Frequency Step	Log
Maximum Change %	27	<input checked="" type="checkbox"/> Operating Point	
Noise Input	NONE	<input type="checkbox"/> Auto Scale Ranges	
Noise Output	2		

P	X Expression	Y Expression	X Range	Y Range
1	F	V(Vo)	FMAX,FMIN	100,0
1	F	68.6	FMAX,FMIN	100,0

The line at the value of 68.6 is at the maximum value of the gain divided by  $\sqrt{2}$ .

Run the Analysis.



Test the circuit and find the two frequencies at which the gain is below the maximum value by a factor of  $\sqrt{2}$ , 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

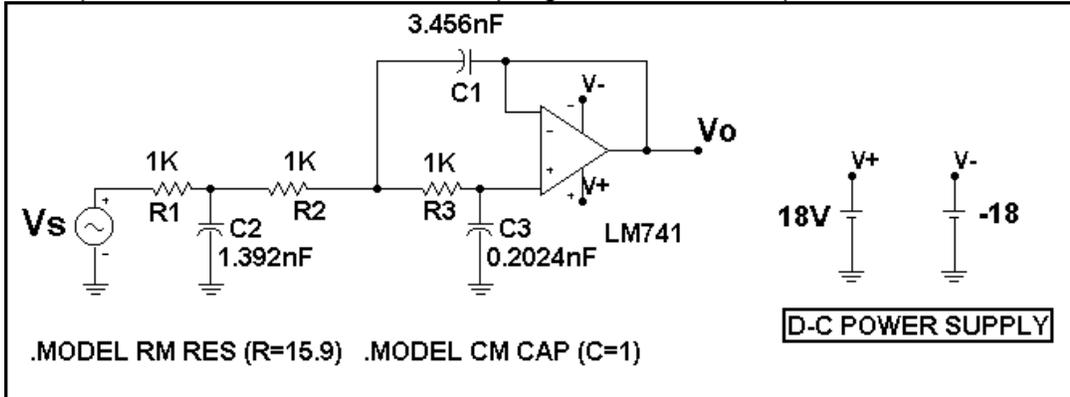
$$[G_5(C_2+C_3)] / (2 \cdot \pi \cdot C_2 \cdot C_3)$$

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  $1K\Omega \cdot R = 15.9\text{ k}\Omega$ .

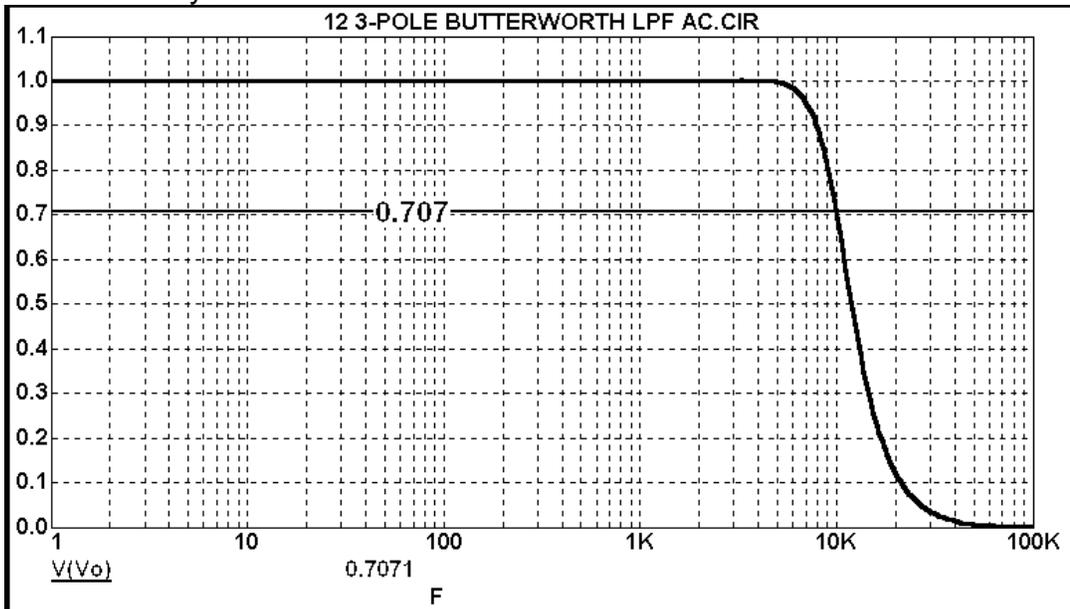
Use these **A-C Analysis Limits**.

Frequency Range	100K,1	Run Options	Normal
Number of Points	511	State Variables	Zero
Temperature	Linear	Frequency Step	Auto
Maximum Change %	1	<input checked="" type="checkbox"/> Operating Point	
Noise Input	Vs	<input type="checkbox"/> Auto Scale Ranges	
Noise Output	Vo		

P	X Expression	Y Expression	X Range	Y Range
1	F	V(Vo)	FMAX,FMIN	1.1,0,0.1
1	F	0.7071	FMAX,FMIN	1.1,0,0.1

Run the Analysis.



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

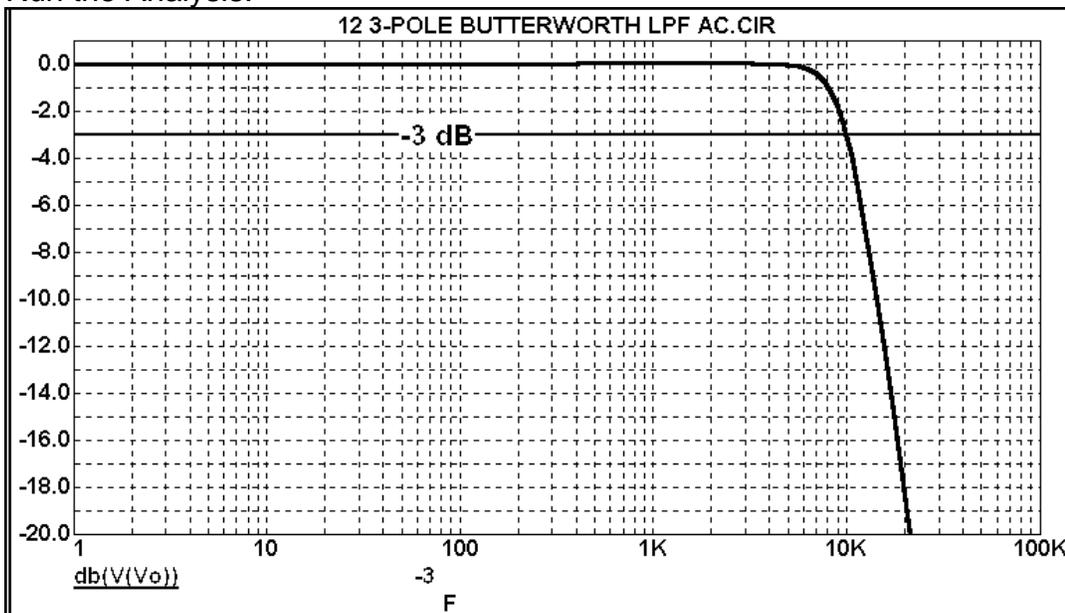
Now use these **A-C Analysis Limits** to display  $V_O$  on a logarithmic ( decibel) scale.

Frequency Range	100K,1	Run Options	Normal
Number of Points	511	State Variables	Zero
Temperature	Linear 27	Frequency Step	Auto
Maximum Change %	1	<input checked="" type="checkbox"/> Operating Point	
Noise Input	Vs	<input type="checkbox"/> Auto Scale Ranges	
Noise Output	Vo		

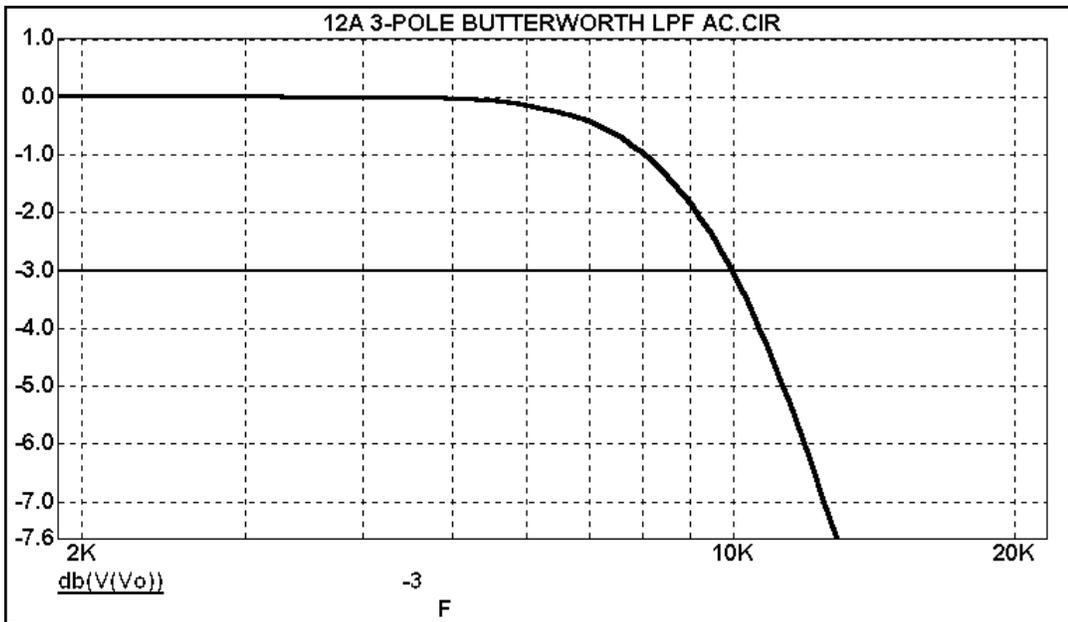
P	X Expression	Y Expression	X Range	Y Range
1	F	db(V{Vo})	FMAX,FMIN	1,-20,1
1	F	-3	FMAX,FMIN	1,-20

Run the Analysis.



The decibel values are given by  $V_O(\text{dB}) = 20 \cdot \text{Log}_{10}(V_O/V_S)$ . 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**

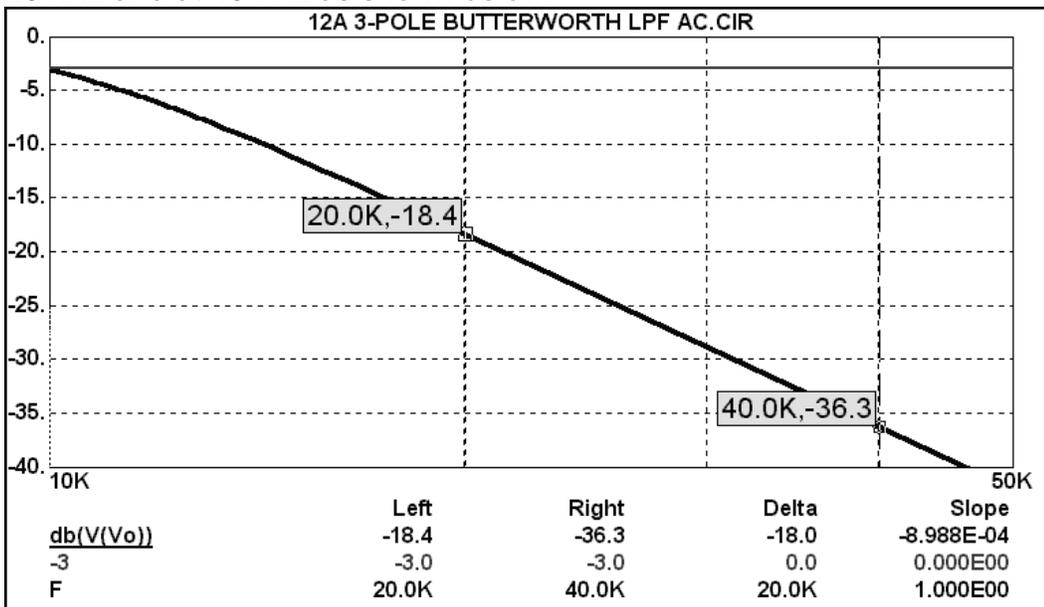
Find the slope of the roll-off in the stop band and compare it to the expected value for a 3-pole filter of  $3 \cdot 20 \text{ dB/decade} = -60 \text{ dB/decade}$  which also corresponds to  $3 \cdot 6 \text{ dB/octave} = -18 \text{ dB/octave}$ , where an octave is a 2:1 frequency ratio. Do this on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

Frequency Range	50K,10K	Run Options	Normal
Number of Points	511	State Variables	Zero
Temperature	Linear 27	Frequency Step	Auto
Maximum Change %	1	<input checked="" type="checkbox"/> Operating Point	
Noise Input	Vs	<input type="checkbox"/> Auto Scale Ranges	
Noise Output	Vo		

P	X Expression	Y Expression	X Range	Y Range
1	F	db(V(Vo))	FMAX,FMIN	0,-40,5
1	F	-3	FMAX,FMIN	0,-40,5

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.

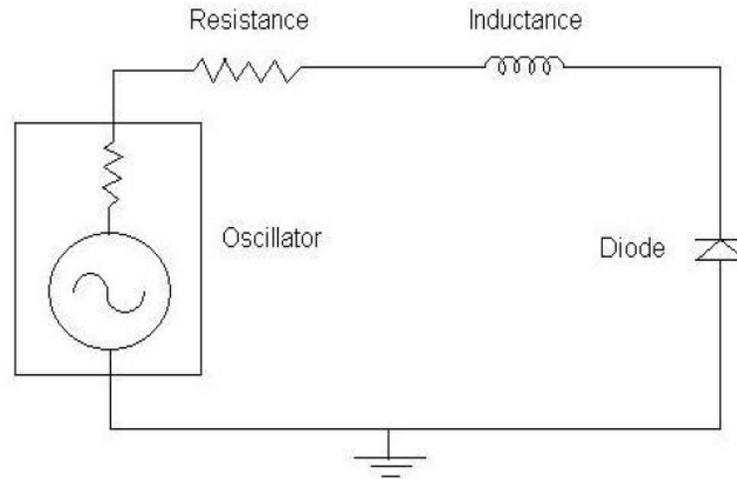
Some of the Navy's highest priorities, such as improved communications, increased bandwidth, improved sensors, and more effective countermeasures for dealing with improvised explosive devices, are currently being addressed by nonlinear dynamics technology.

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:

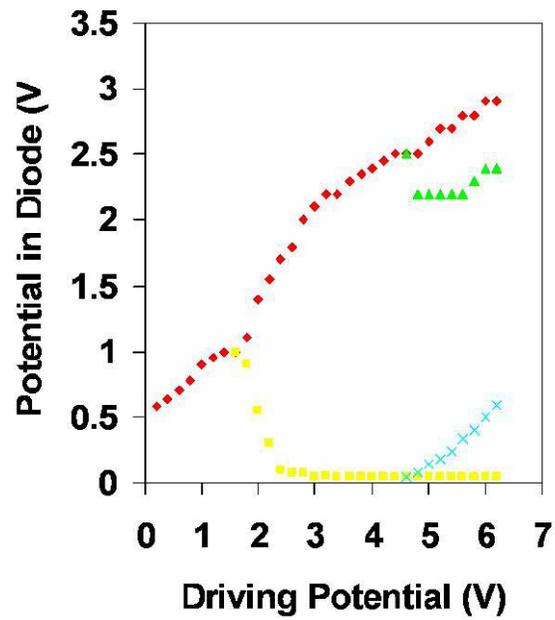
- Resistance: 200  $\Omega$ , 5% tolerance (if not 5% it is O.K.)
- Inductance: 25 mH
- Diode: any silicon diode would do (e.g., 1N..)

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.

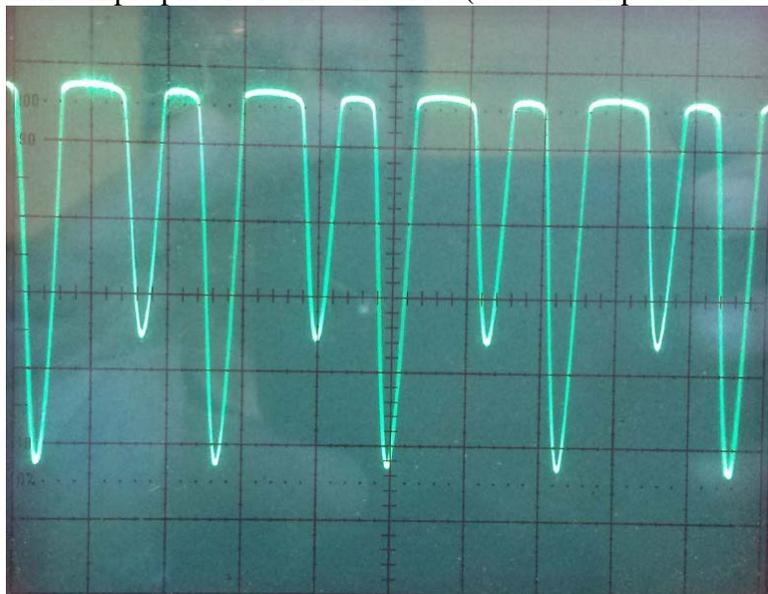
## Experimental Procedure:

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:

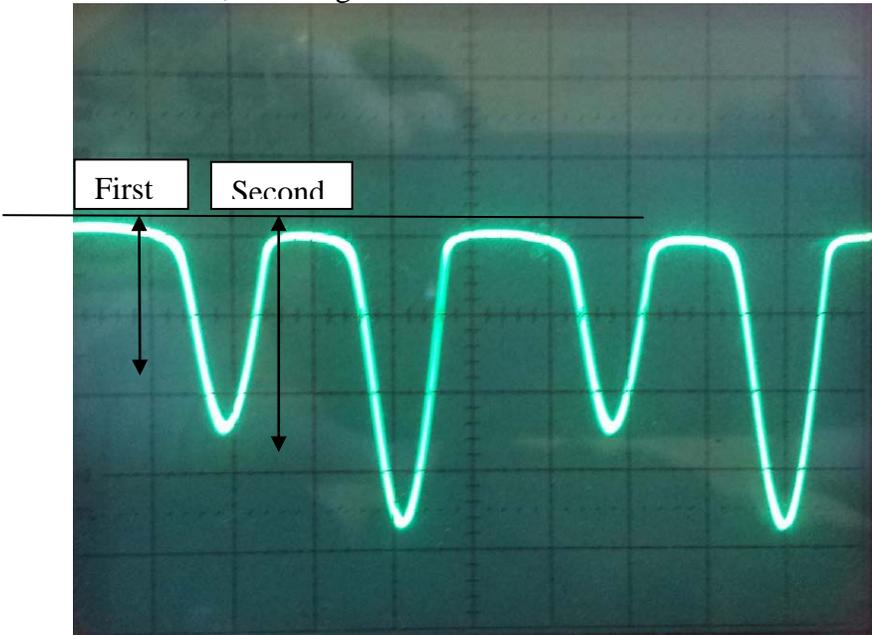


5. Increase the input voltage amplitude from the 100 mV PP level in increments of 200 mV PP and measure the PP output voltage across the diode. Typical pictures that identify various Bifurcation levels are shown below.

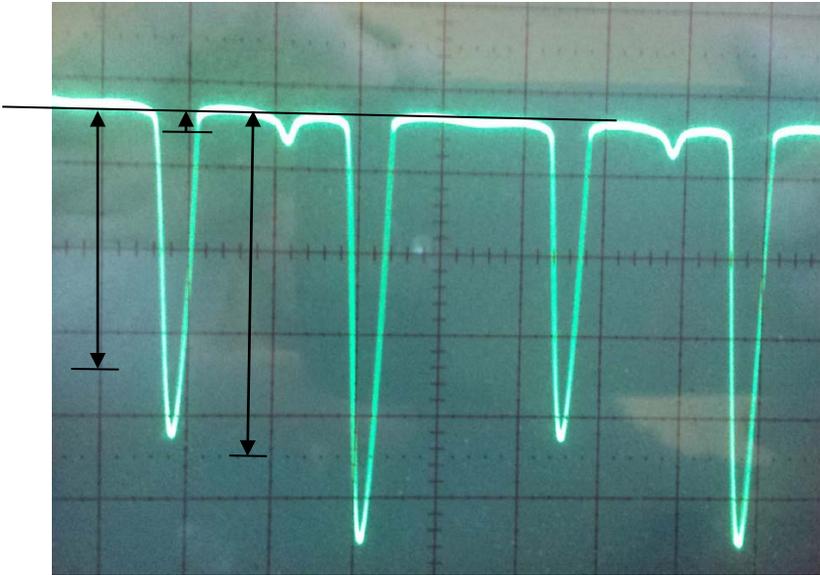
The First level Bifurcation sample picture is shown below (occurs at input of about 1.8 V PP):



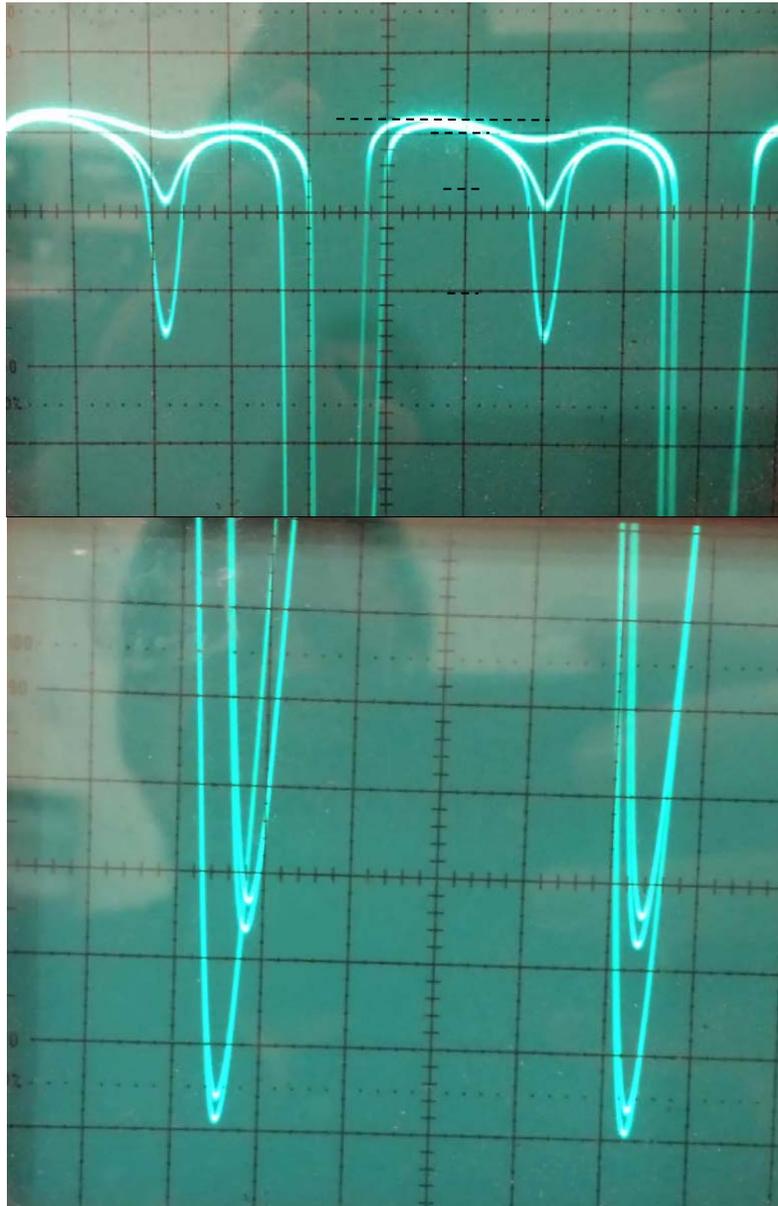
To measure the bifurcation levels, use the guide below:



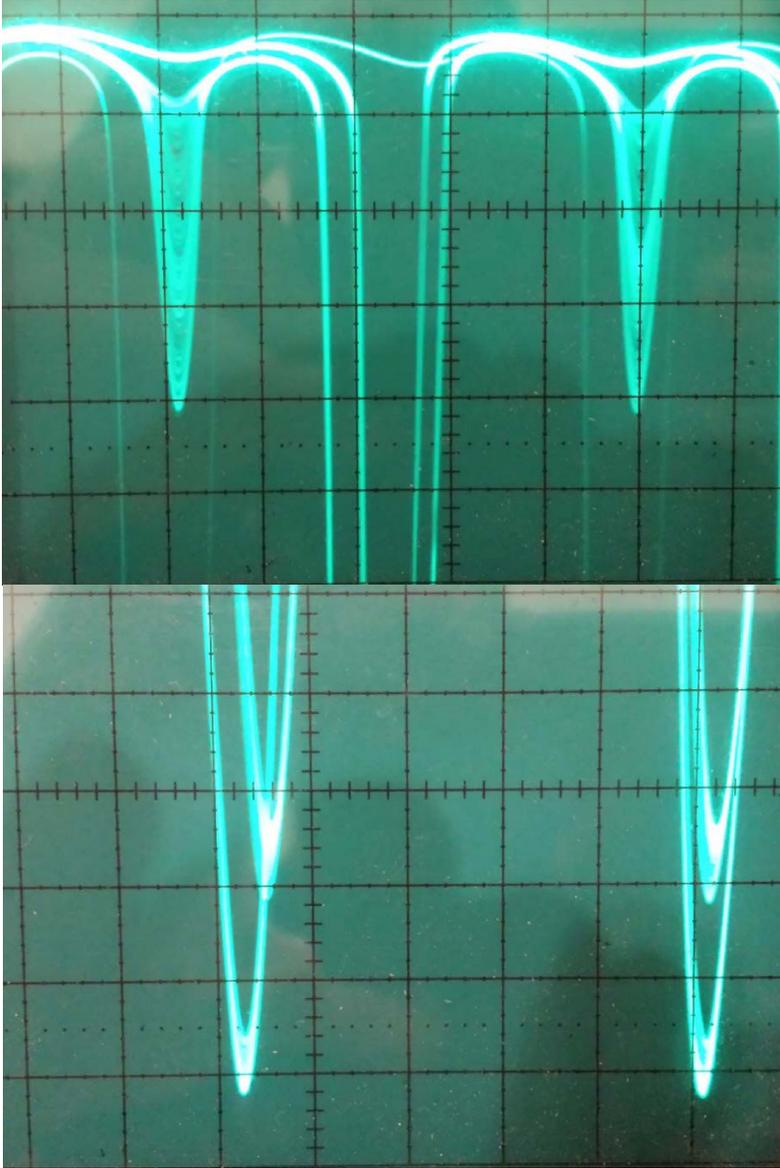
The 2<sup>nd</sup> level bifurcation picture and the corresponding levels is shown below (occurs at input voltage of about 4.8 V PP):



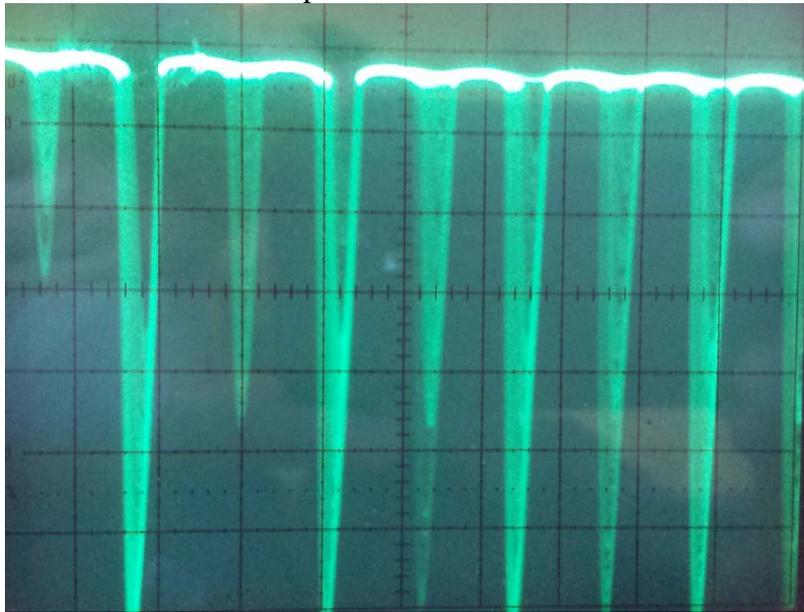
The Third level Bifurcation (occurs at input voltage level of about 5.6 V PP) may not produce a steady single trace picture. Nonetheless, it is possible to clearly identify splitting of the levels to produce 8 potential levels. The lowest level is very near zero. The other low levels show up as dips 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:

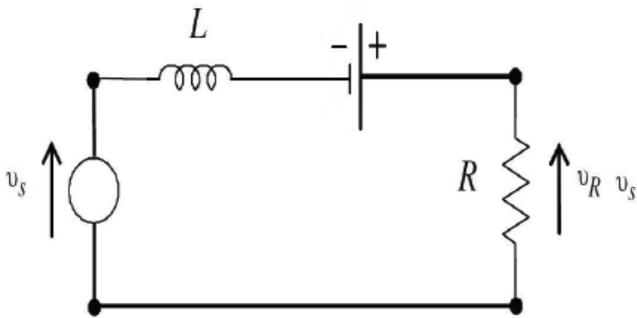


At deep Chaos, the levels can be all over the place:

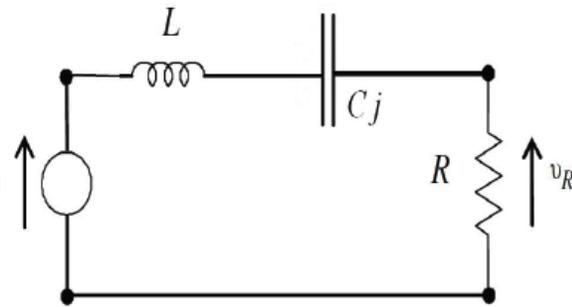


**Analysis:**

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:

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

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:

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

Where,  $B$  and  $\varphi$  are constants to be determined from initial conditions and

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

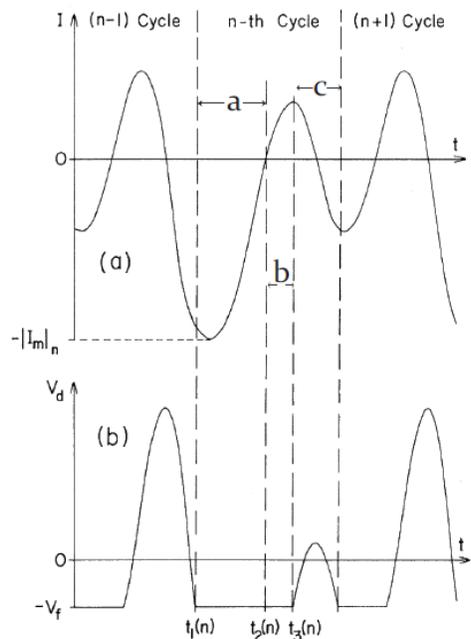
$$Z_b = \sqrt{R^2 + \frac{L^2}{R^2}(\omega^2 - \omega_o^2)^2}$$

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  $\tau$  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,  $\tau_m$  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 to 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  $Q = \frac{f_0}{(f_u - f_l)}$ , and compare the value to the theory given by  $Q = \frac{\omega_0 L}{R}$ ;
2. From the measured resonance frequency, determine the junction capacitance from  $\omega_0 = \frac{1}{\sqrt{LC_j}}$ ;
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  $\tau_m$  and  $I_C$  for the diode you are using.