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**Analog Electronics Lab #2 – Common Collector Amplifier, Darlington pair, Bootstrap configuration**

## Objectives

Design the provided circuit on LT Spice and calculate the following parameters

1. Voltage gain
2. Input Resistance
3. Output Resistance
4. Input voltage and current
5. Output voltage and current
6. Show input and output waveform

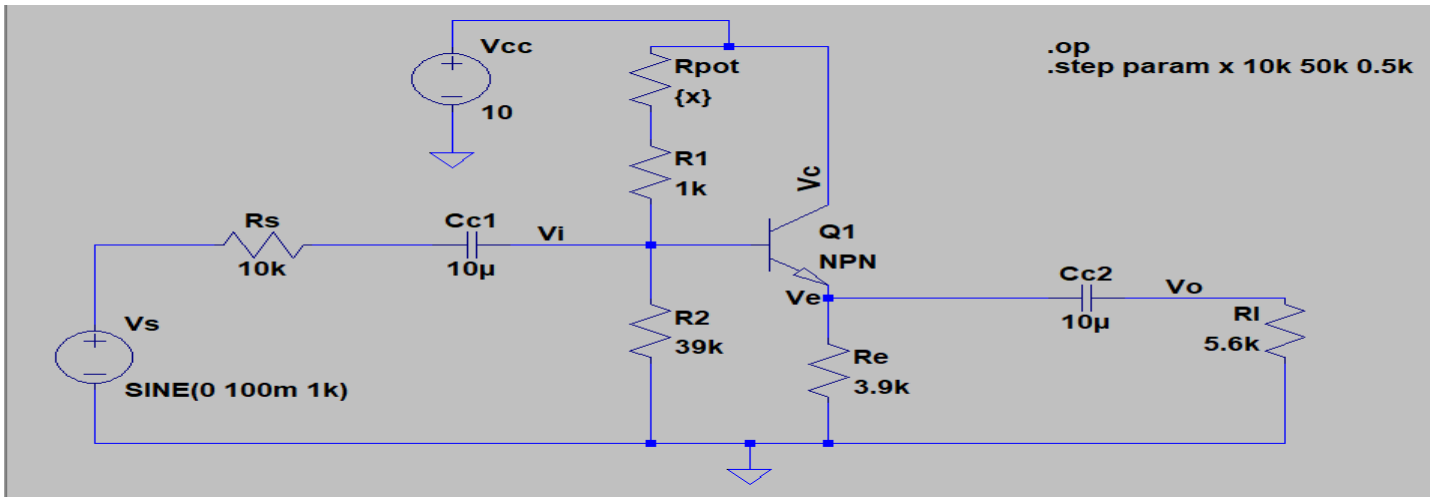
for the following three configurations:

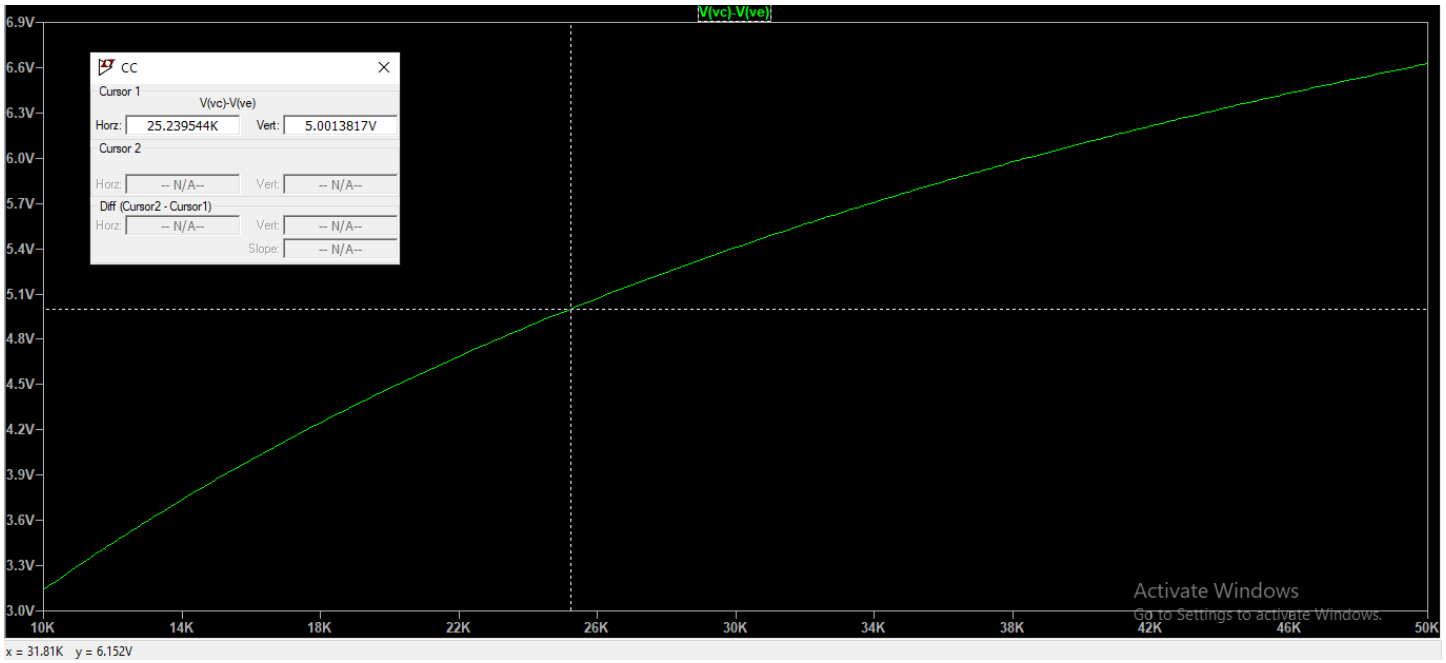
a) Common collector,
b) Darlington pair,
c) Bootstrap configuration.

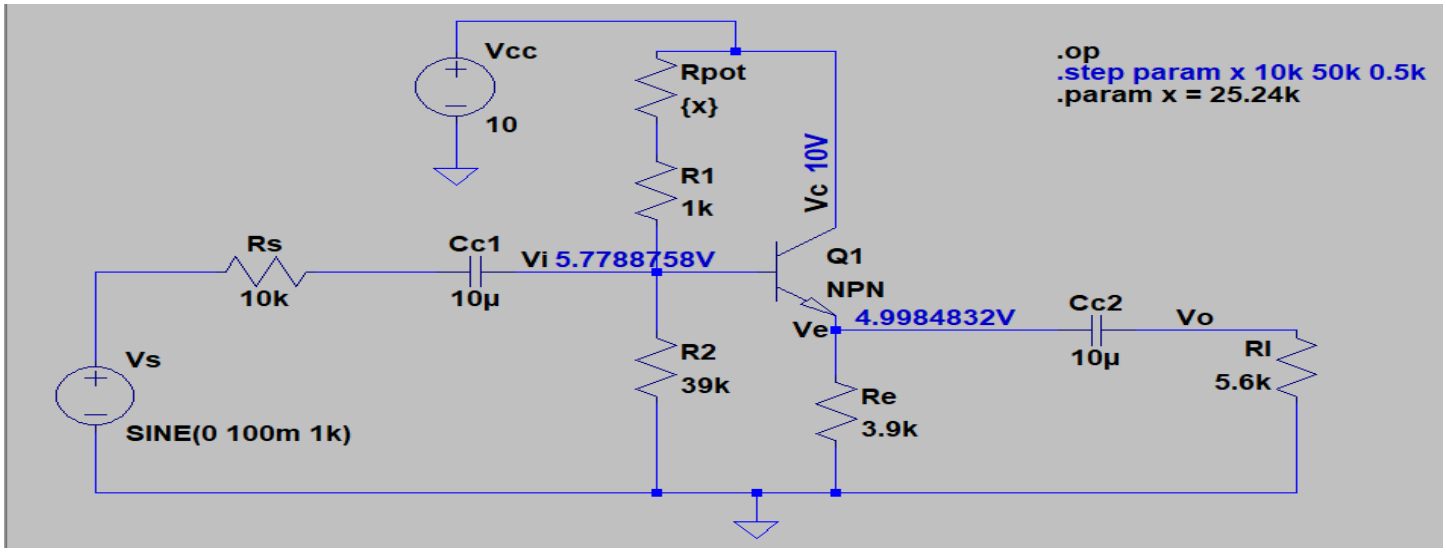
at an operating point Vce = Vcc/2. Also, record observations and write conclusions for each amplifier configuration.

# Common Collector

# Finding the value of potentiometer resistance




DC analysis using .op gives Rpot = 25.24 kΩ (total = 26.24 kΩ) for Vce = 5V.

# AC analysis to find voltage gain, Iin, Iout, Vin, Vout at f = 1kHz (.ac lin 1 1k 1k)

Gain = V(vo)/V(vi) = 0.0589986/0.0595167 = 0.9913 = -0.076 dB
Gain (Ai) = Ie(Q1)/Ib(Q1) = 25.6633uA/0.254092uA = 101 = 40.1 dB

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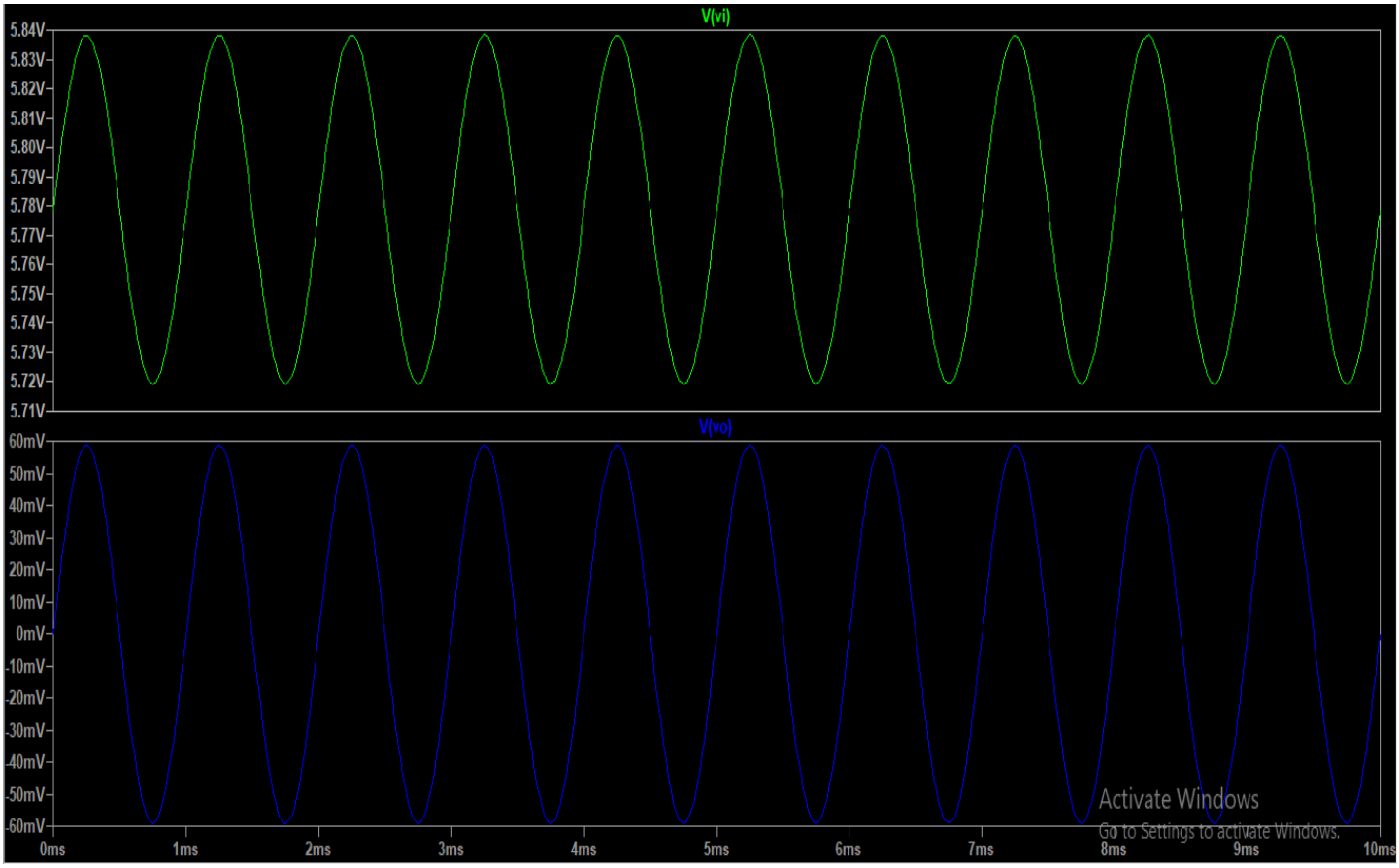
```
      --- AC Analysis ---

frequency:     1000          Hz
V(vc):         mag:          0 phase:          0°          voltage
V(vi):         mag:  0.0595167 phase:  0.0352325°          voltage
V(ve):         mag:  0.0589988 phase:  0.0346508°          voltage
V(n001):       mag:  0.0572485 phase:  0.0352325°          voltage
V(vo):         mag:  0.0589986 phase:   0.197488°          voltage
V(n003):       mag:  0.0595167 phase: -0.0267943°          voltage
V(n002):       mag:        0.1 phase:          0°          voltage
Ic(Q1):        mag: 2.54092e-005 phase:     0.1015°        device_current
Ib(Q1):        mag: 2.54092e-007 phase:     0.1015°        device_current
Ie(Q1):        mag: 2.56633e-005 phase:    -179.899°       device_current
I(Cc1):        mag: 4.04833e-006 phase:    -179.961°       device_current
I(Cc2):        mag: 1.05355e-005 phase:    -179.803°       device_current
I(Rs):         mag: 4.04833e-006 phase:    -179.961°       device_current
I(Rl):         mag: 1.05355e-005 phase:    -179.803°       device_current
I(Re):         mag: 1.51279e-005 phase:   0.0346508°       device_current
I(R2):         mag: 1.52607e-006 phase:   0.0352325°       device_current
I(Rpot):       mag: 2.26817e-006 phase:    -179.965°       device_current
I(Rl):         mag: 2.26817e-006 phase:    -179.965°       device_current
I(Vcc):        mag: 2.31411e-005 phase:    -179.892°       device_current
I(Vs):         mag: 4.04833e-006 phase:    -179.961°       device_current
```

**Other parameters:**

Vin = 0.0595167 V ∡ 0.0352325°
Iin = 4.04833 μA ∡ -179.961°
Vout = 0.0589986 V ∡ 0.197488°
Iout = 10.5355 μA ∡ -179.803°

# Input and Output waveforms
# (.tran 10m)



# Input resistance ($R_{in}$)

**DC input resistance**: infinite (as input capacitor blocks all dc voltage)

**AC input resistance**:

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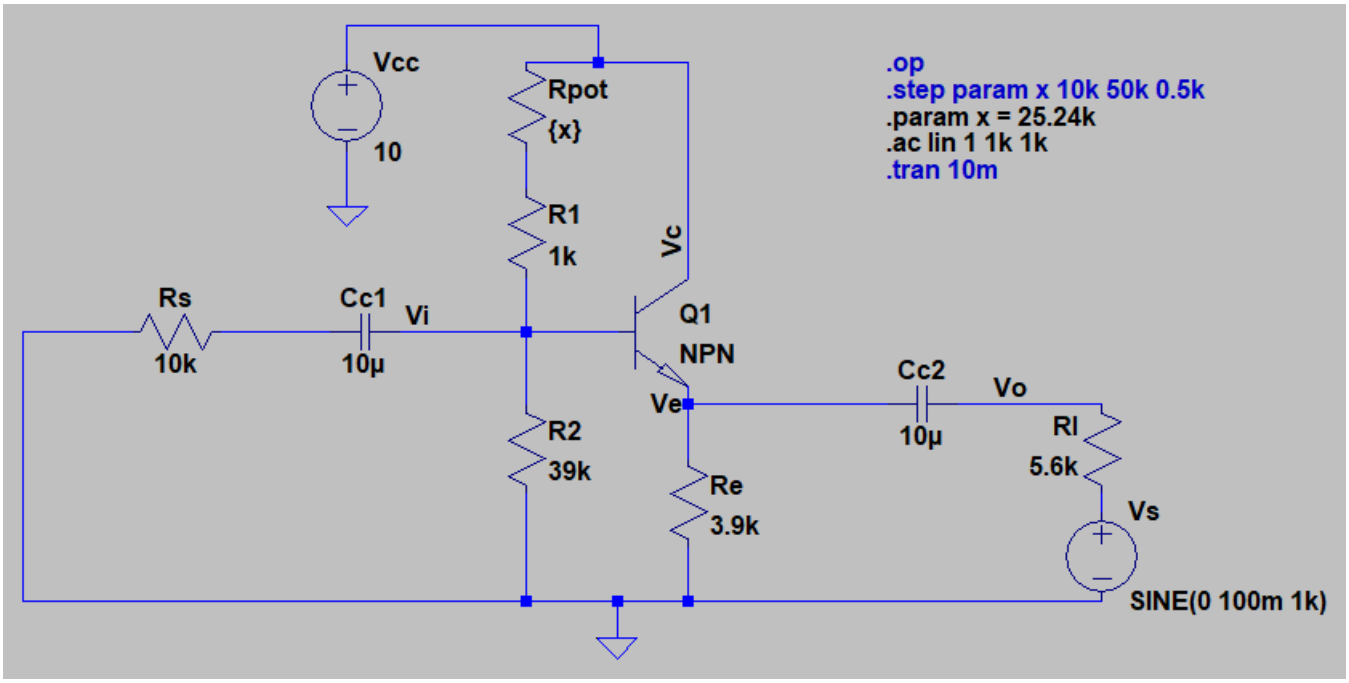
```
      --- AC Analysis ---

frequency:     1000          Hz
V(vc):         mag:          0 phase:          0°          voltage
V(vi):         mag:  0.0595167 phase:  0.0352325°          voltage
V(ve):         mag:  0.0589988 phase:  0.0346508°          voltage
V(n001):       mag:  0.0572485 phase:  0.0352325°          voltage
V(vo):         mag:  0.0589986 phase:   0.197488°          voltage
V(n003):       mag:  0.0595167 phase: -0.0267943°          voltage
V(n002):       mag:        0.1 phase:          0°          voltage
Ic(Q1):        mag: 2.54092e-005 phase:     0.1015°        device_current
Ib(Q1):        mag: 2.54092e-007 phase:     0.1015°        device_current
Ie(Q1):        mag: 2.56633e-005 phase:   -179.899°        device_current
I(Cc1):        mag: 4.04833e-006 phase:   -179.961°        device_current
I(Cc2):        mag: 1.05355e-005 phase:   -179.803°        device_current
I(Rs):         mag: 4.04833e-006 phase:   -179.961°        device_current
I(Rl):         mag: 1.05355e-005 phase:   -179.803°        device_current
I(Re):         mag: 1.51279e-005 phase:  0.0346508°        device_current
I(R2):         mag: 1.52607e-006 phase:  0.0352325°        device_current
I(Rpot):       mag: 2.26817e-006 phase:   -179.965°        device_current
I(Rl):         mag: 2.26817e-006 phase:   -179.965°        device_current
I(Vcc):        mag: 2.31411e-005 phase:   -179.892°        device_current
I(Vs):         mag: 4.04833e-006 phase:   -179.961°        device_current
```

$$R_{in} = \frac{V_{in}}{I_{in}} = \frac{V(vi)}{I(Vs)} = \frac{0.0595167}{4.04833 \times 10^{-6}} = 14.7\ k\Omega$$

# Output resistance ($R_{out}$)

**DC output resistance**: 5.6 kΩ

**AC output resistance**:

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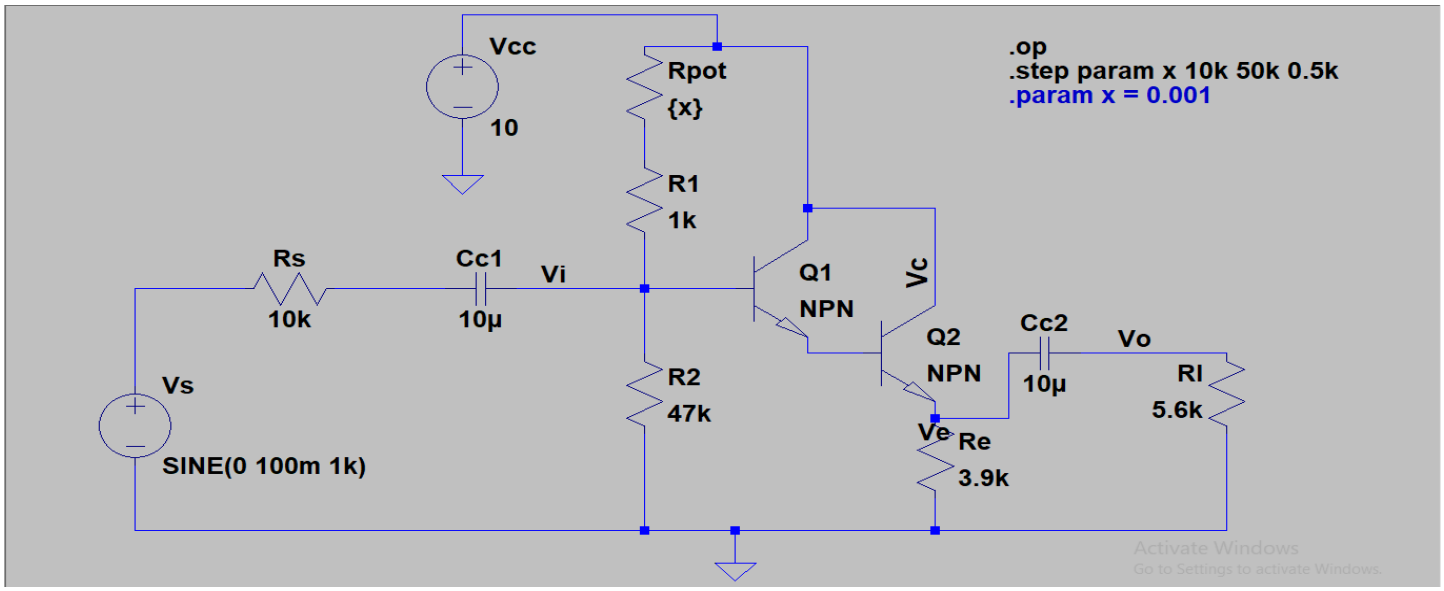
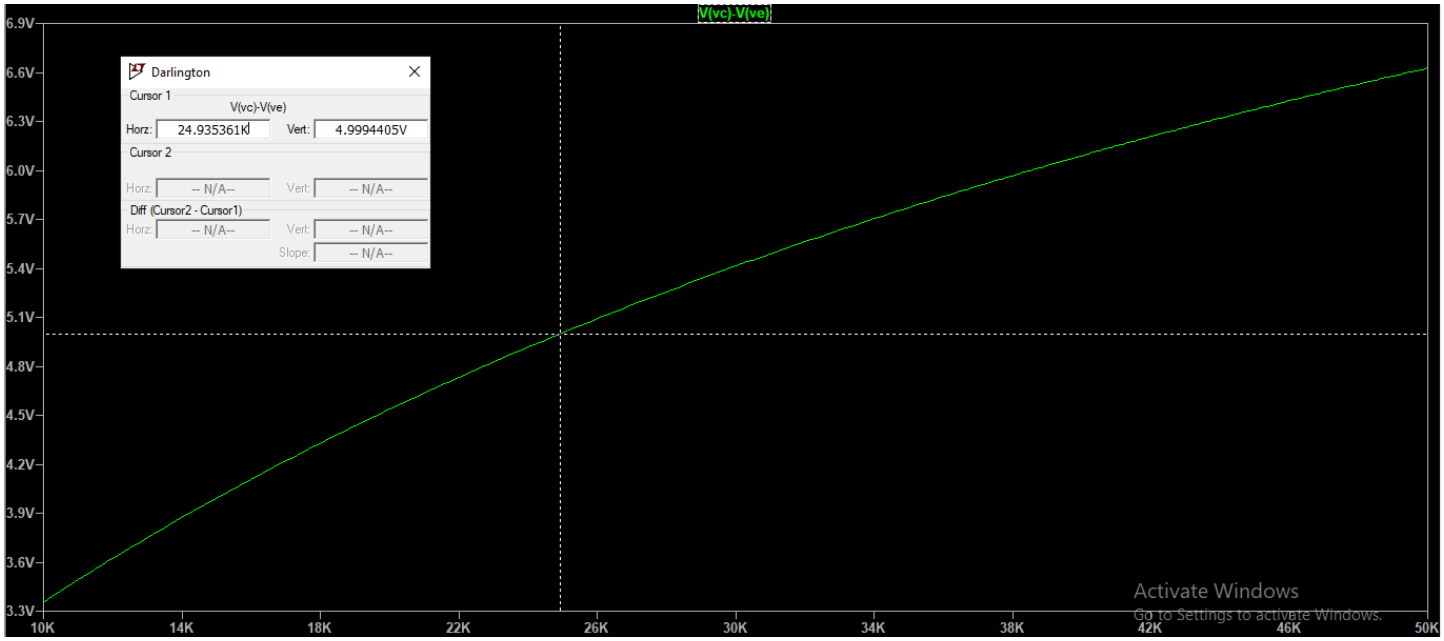
```
      --- AC Analysis ---

frequency:     1000          Hz
V(vc):         mag:          0 phase:          0°          voltage
V(vi):         mag: 0.00104312 phase:   0.106299°          voltage
V(ve):         mag: 0.00139127 phase:   0.120234°          voltage
V(n001):       mag: 0.00100336 phase:   0.106299°          voltage
V(n003):       mag:        0.1 phase:          0°          voltage
V(vo):         mag: 0.00141941 phase:   -11.2671°          voltage
V(n002):       mag: 0.00104311 phase:   0.197488°          voltage
Ic(Q1):        mag: 1.70811e-005 phase:   -179.838°        device_current
Ib(Q1):        mag: 1.70811e-007 phase:   -179.838°        device_current
Ie(Q1):        mag: 1.72519e-005 phase:   0.161987°        device_current
I(Cc1):        mag: 1.04311e-007 phase:   0.197488°        device_current
I(Cc2):        mag: 1.76086e-005 phase:   0.161141°        device_current
I(Rs):         mag: 1.04311e-007 phase:   0.197488°        device_current
I(Rl):         mag: 1.76086e-005 phase:   0.161141°        device_current
I(Re):         mag: 3.56736e-007 phase:   0.120234°        device_current
I(R2):         mag: 2.67466e-008 phase:   0.106299°        device_current
I(Rpot):       mag: 3.97529e-008 phase:   -179.894°        device_current
I(R1):         mag: 3.97529e-008 phase:   -179.894°        device_current
I(Vcc):        mag: 1.71208e-005 phase:   0.161857°        device_current
I(Vs):         mag: 1.76086e-005 phase:   -179.839°        device_current
```

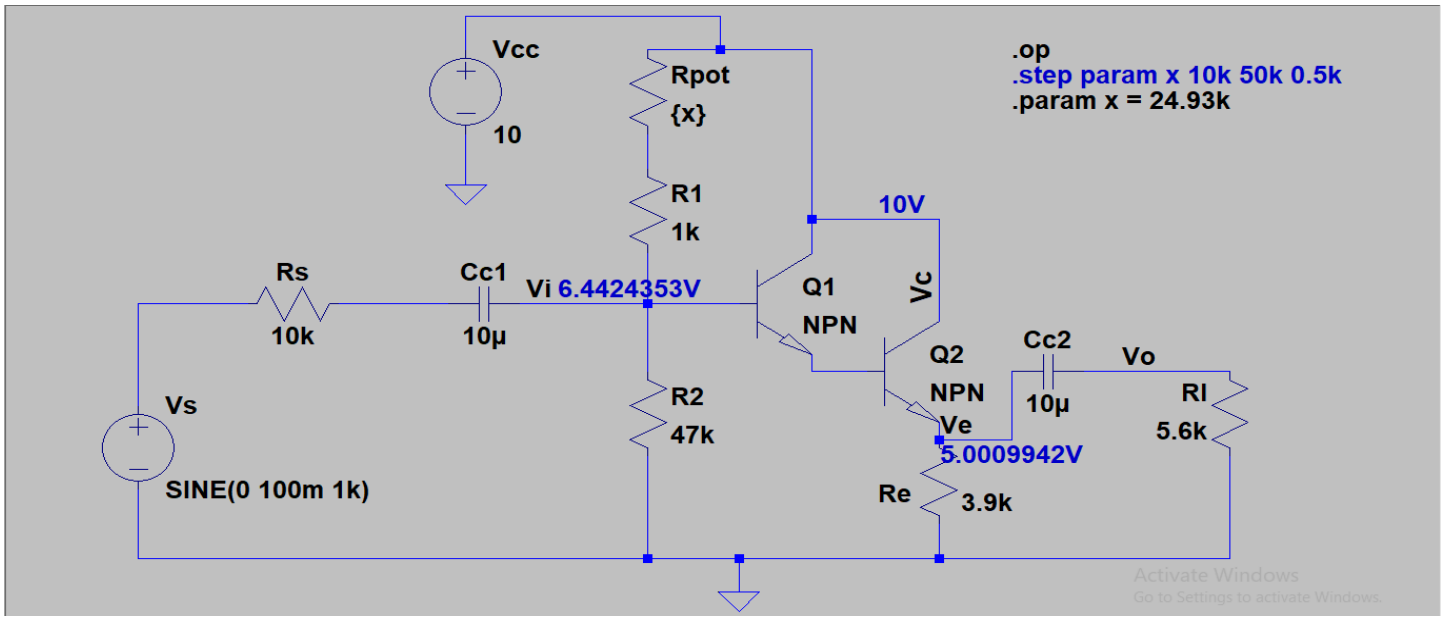
$$R_{out} = \frac{V_{out}}{I_{out}} = \frac{V(vo)}{I(Vs)} = \frac{0.00141941}{1.76086 \times 10^{-5}} = 80.61\ \Omega$$

# Darlington Pair

# Finding the value of potentiometer resistance




DC analysis using .op gives Rpot = 24.93 kΩ (total = 25.93 kΩ) for Vce = 5V.

# AC analysis to find voltage gain, Iin, Iout, Vin, Vout at f = 1kHz (.ac lin 1 1k 1k)

Gain (Av) = V(vo)/V(vi) = 0.0614665/0.0625454 = 0.983 = -0.151 dB
Gain (Ai) = Ie(Q2)/Ib(Q1) = 26.7369uA/2.62107nA = 10200.76 = 80.17 dB

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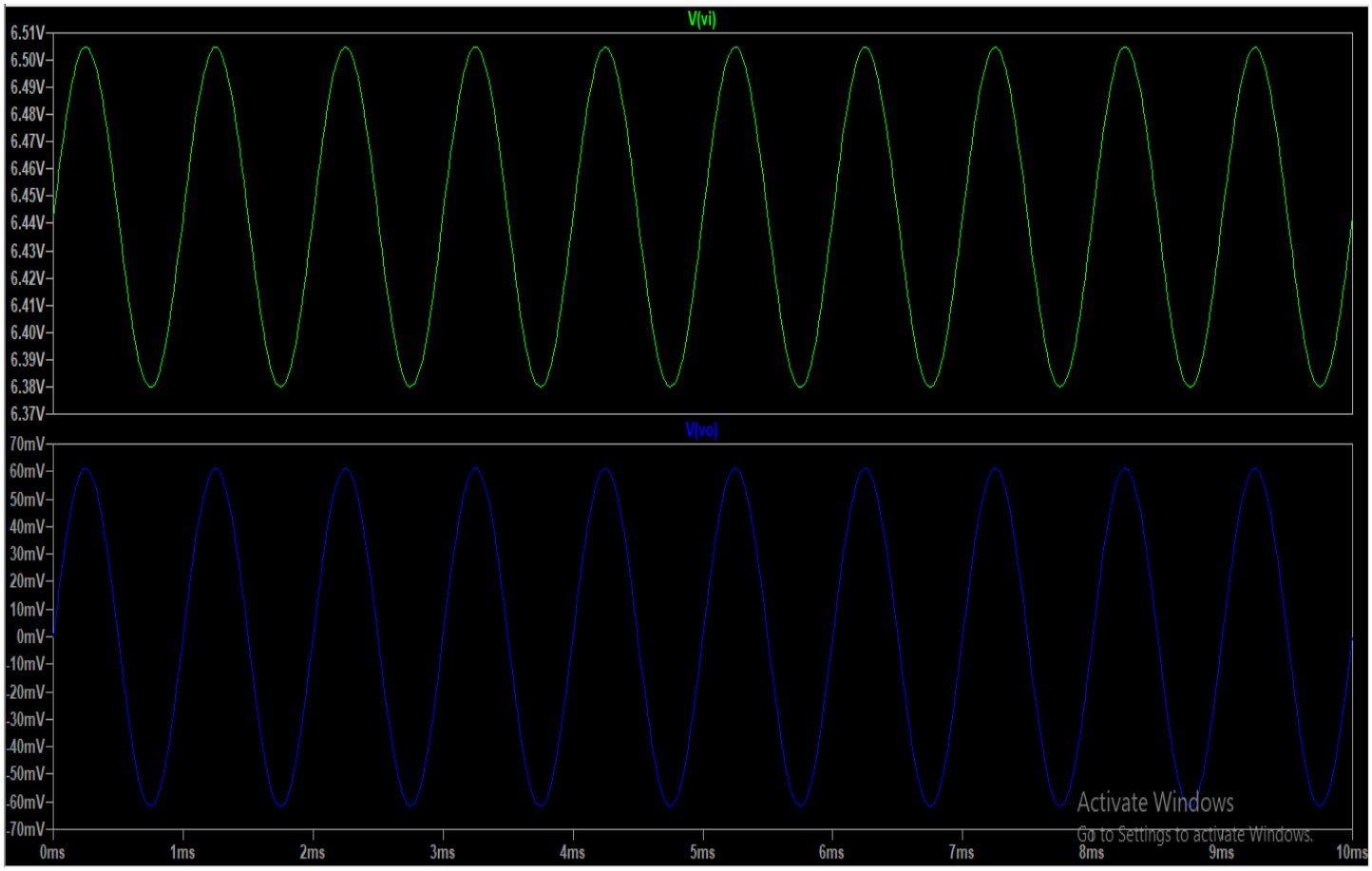
```
       --- AC Analysis ---

frequency:     1000          Hz
V(vc):         mag:          0 phase:           0°          voltage
V(vi):         mag:  0.0625454 phase:  0.0341373°          voltage
V(n004):       mag:  0.0620061 phase:  0.0335659°          voltage
V(n001):       mag:  0.0601333 phase:  0.0341373°          voltage
V(ve):         mag:  0.0614668 phase:  0.0329845°          voltage
V(vo):         mag:  0.0614665 phase:   0.195822°          voltage
V(n003):       mag:  0.0625454 phase: -0.0204702°          voltage
V(n002):       mag:        0.1 phase:           0°          voltage
Ic(Q2):        mag: 2.64721e-005 phase:  0.0998332°        device_current
Ib(Q2):        mag: 2.64721e-007 phase:  0.0998332°        device_current
Ie(Q2):        mag: 2.67369e-005 phase:     -179.9°        device_current
Ic(Q1):        mag: 2.621e-007 phase:  0.0998332°          device_current
Ib(Q1):        mag: 2.62107e-009 phase:  0.0998317°        device_current
Ie(Q1):        mag: 2.64721e-007 phase:     -179.9°        device_current
I(Cc1):        mag: 3.74546e-006 phase:   -179.966°        device_current
I(Cc2):        mag: 1.09762e-005 phase:   -179.804°        device_current
I(Rs):         mag: 3.74546e-006 phase:   -179.966°        device_current
I(Rl):         mag: 1.09762e-005 phase:   -179.804°        device_current
I(Re):         mag: 1.57607e-005 phase:  0.0329845°        device_current
I(R2):         mag: 1.33075e-006 phase:  0.0341373°        device_current
I(Rpot):       mag: 2.41209e-006 phase:   -179.966°        device_current
I(R1):         mag: 2.41209e-006 phase:   -179.966°        device_current
I(Vcc):        mag: 2.43222e-005 phase:   -179.894°        device_current
I(Vs):         mag: 3.74546e-006 phase:   -179.966°        device_current
```

**Other parameters:**

Vin = 0.0625454 V ∡ 0.0341373°
Iin = 3.74546 µA ∡ -179.966°
Vout = 0.0614665 V ∡ 0.195822°
Iout = 10.9762 µA ∡ -179.804°

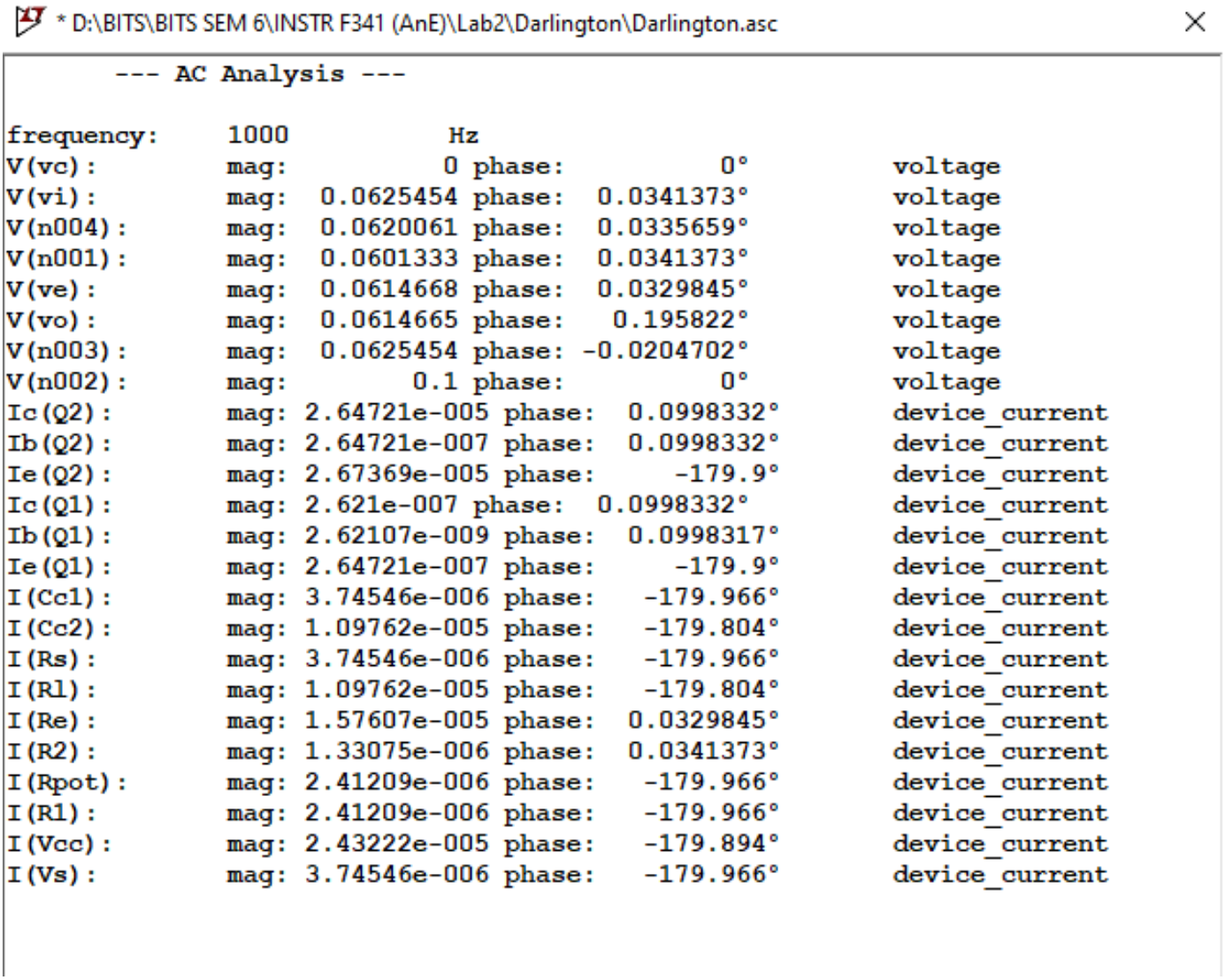
# Input and Output waveforms
# (.tran 10m)



# Input resistance ($R_{in}$)

**DC input resistance**: infinite (as input capacitor blocks all dc voltage)

**AC input resistance**:

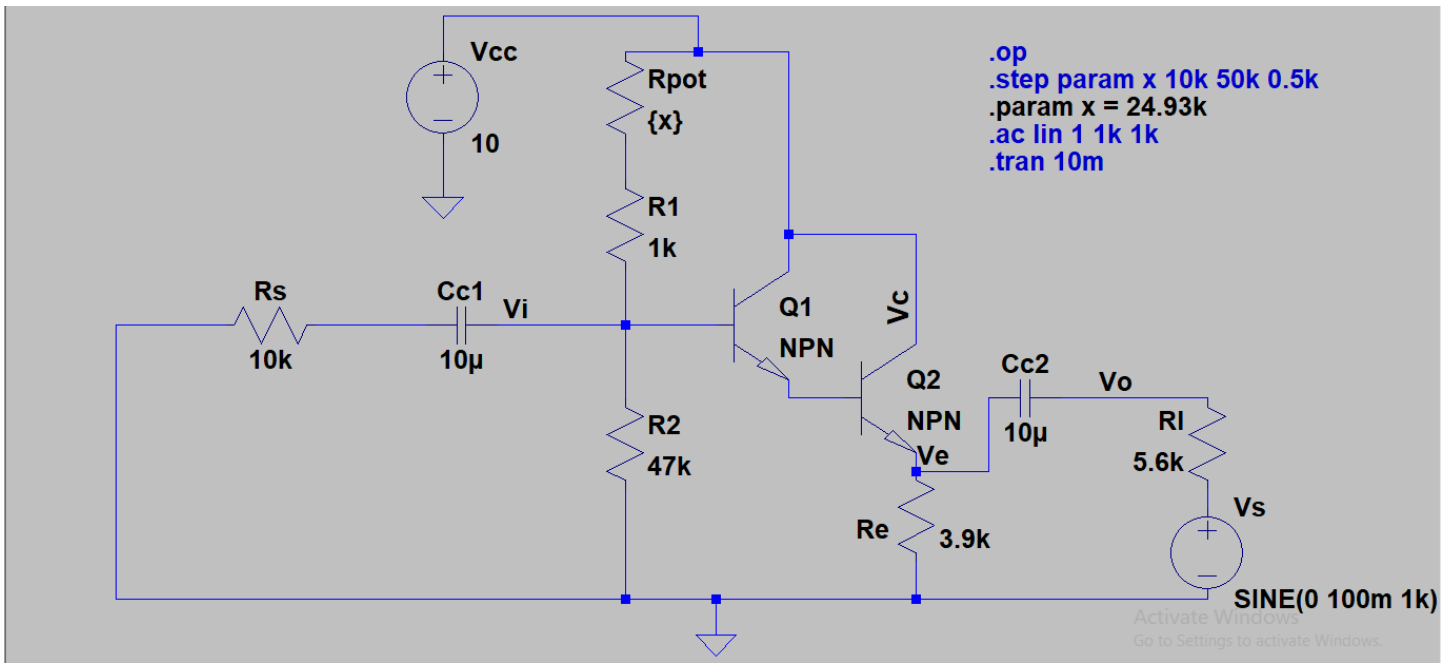



$$R_{in} = \frac{V_{in}}{I_{in}} = \frac{V(vi)}{I(Vs)} = \frac{0.0625454}{3.74546 \times 10^{-6}} = 16.7\ k\Omega$$

# Output resistance ($R_{out}$)

**DC output resistance**: 5.6 kΩ

**AC output resistance**:

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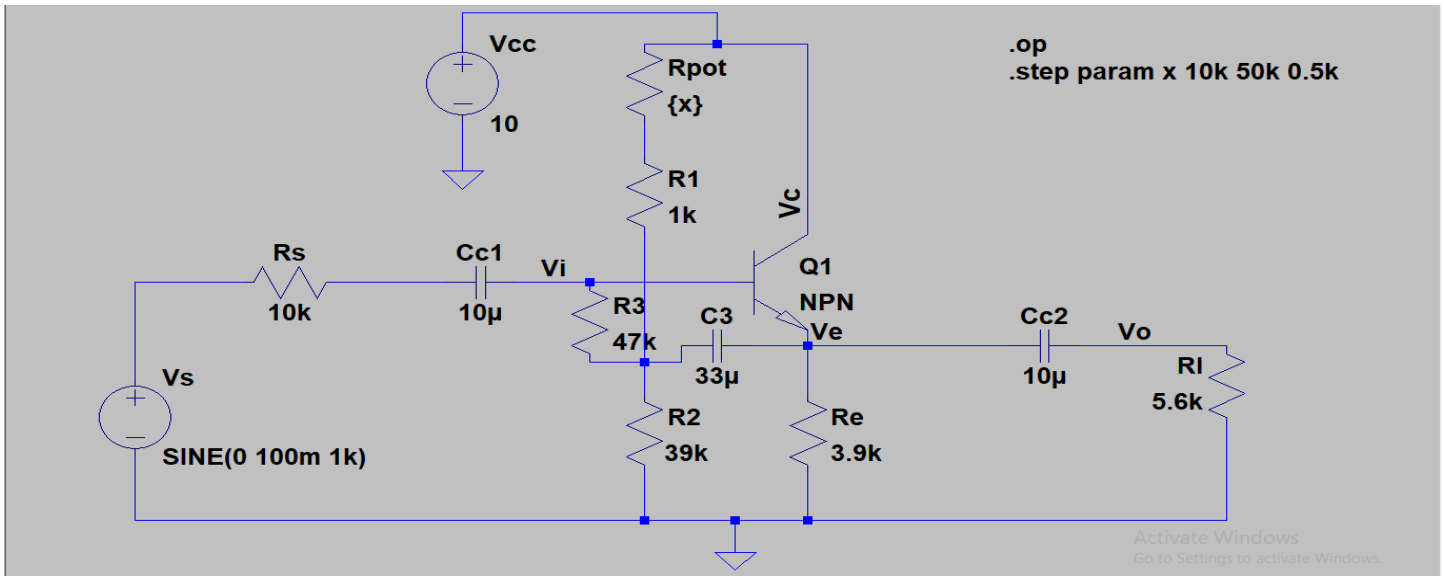
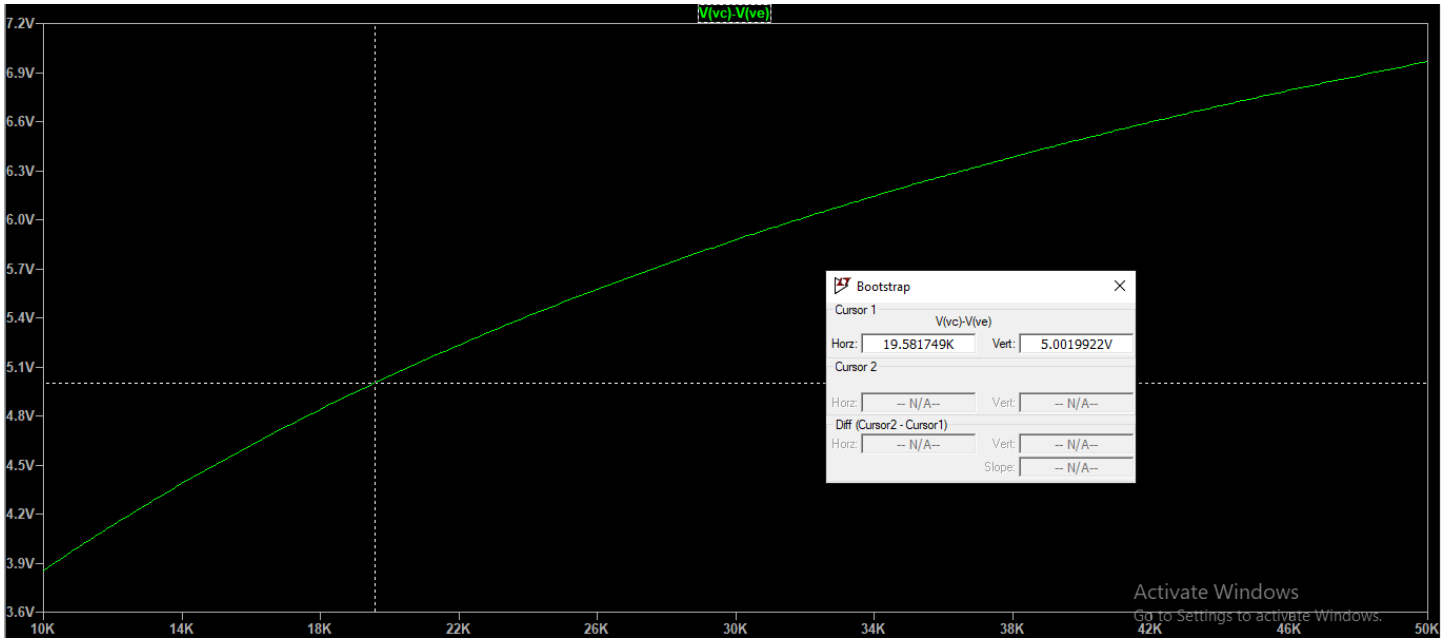
```
      --- AC Analysis ---

frequency:     1000          Hz
V(vc):         mag:          0 phase:          0°          voltage
V(vi):         mag: 1.07599e-005 phase:   0.104633°        voltage
V(n003):       mag: 0.000364645 phase:   0.159999°        voltage
V(n001):       mag: 1.03449e-005 phase:   0.104633°        voltage
V(ve):         mag: 0.000718529 phase:   0.160828°        voltage
V(n004):       mag:        0.1 phase:          0°          voltage
V(vo):         mag: 0.000771949 phase:   -21.2787°        voltage
V(n002):       mag: 1.07599e-005 phase:   0.195822°        voltage
Ic(Q2):        mag: 1.73708e-005 phase:   -179.838°        device_current
Ib(Q2):        mag: 1.73708e-007 phase:   -179.838°        device_current
Ie(Q2):        mag: 1.75445e-005 phase:   0.161682°        device_current
Ic(Q1):        mag: 1.71988e-007 phase:   -179.838°        device_current
Ib(Q1):        mag: 1.71988e-009 phase:   -179.838°        device_current
Ie(Q1):        mag: 1.73708e-007 phase:   0.161682°        device_current
I(Cc1):        mag: 1.07599e-009 phase:   0.195822°        device_current
I(Cc2):        mag: 1.77288e-005 phase:   0.161673°        device_current
I(Rs):         mag: 1.07599e-009 phase:   0.195822°        device_current
I(Rl):         mag: 1.77288e-005 phase:   0.161673°        device_current
I(Re):         mag: 1.84238e-007 phase:   0.160828°        device_current
I(R2):         mag: 2.28934e-010 phase:   0.104633°        device_current
I(Rpot):       mag: 4.1496e-010 phase:   -179.895°         device_current
I(R1):         mag: 4.1496e-010 phase:   -179.895°         device_current
I(Vcc):        mag: 1.75432e-005 phase:   0.161681°        device_current
I(Vs):         mag: 1.77288e-005 phase:   -179.838°        device_current
```

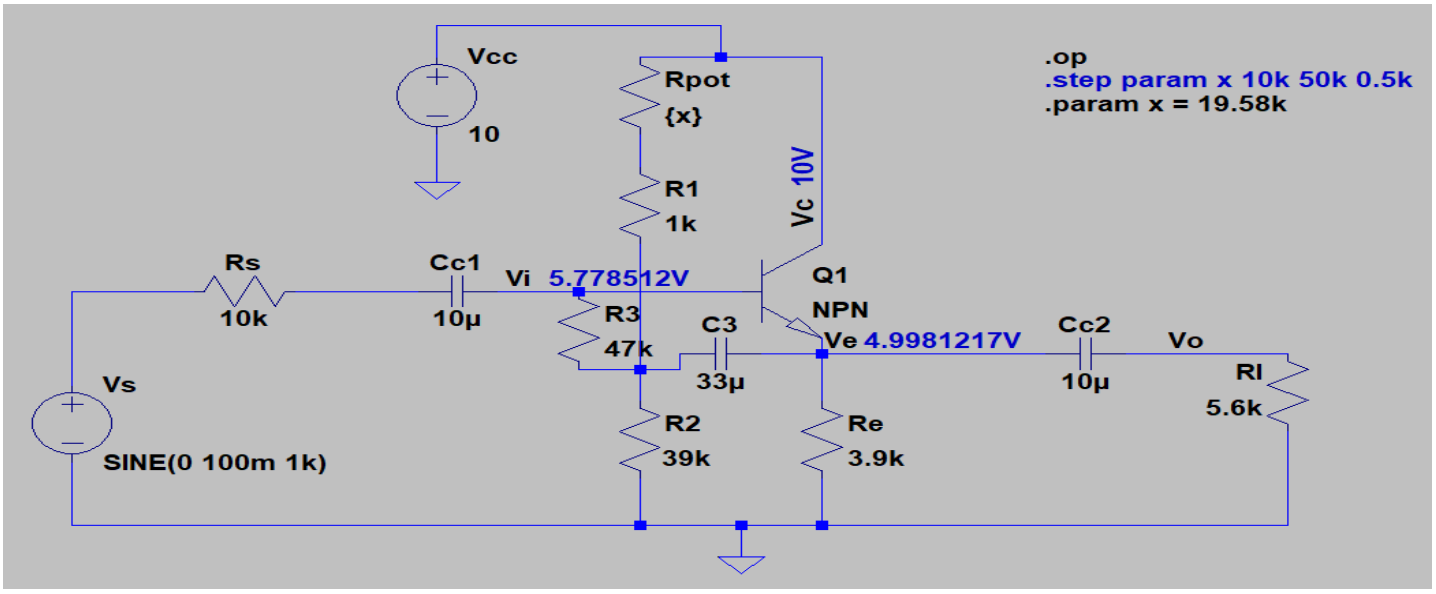
$$R_{out} = \frac{V_{out}}{I_{out}} = \frac{V(vo)}{I(Vs)} = \frac{0.000771949}{1.77288 \times 10^{-5}} = 43.54\ \Omega$$

# Bootstrap Configuration

# Finding the value of potentiometer resistance




DC analysis using .op gives Rpot = 19.58 kΩ (total = 20.58 kΩ) for Vce = 5V.

# AC analysis to find voltage gain, Iin, Iout, Vin, Vout at f = 1kHz (.ac lin 1 1k 1k)

Gain = V(vo)/V(vi) = 0.0940859/0.0950528 = 0.9898 = -0.089 dB
Gain (Ai) = Ie(Q1)/Ib(Q1) = 47.8894uA/0.474152uA = 101 = 40.1 dB

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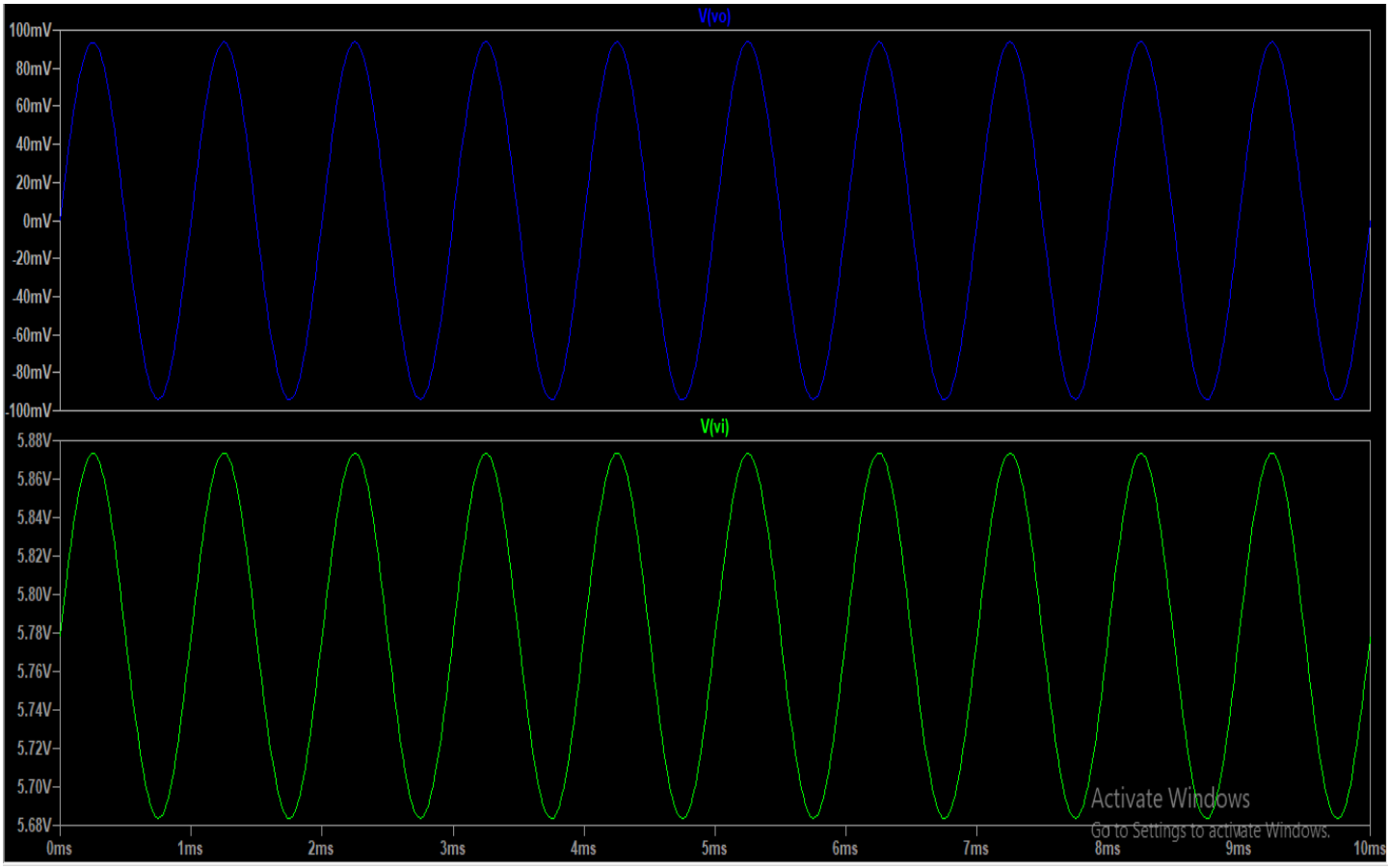
```
      --- AC Analysis ---

frequency:     1000          Hz
V(vc):         mag:          0 phase:          0°          voltage
V(vi):         mag:  0.0950528 phase: 0.00562132°          voltage
V(ve):         mag:  0.0940863 phase: 0.00500168°          voltage
V(n001):       mag:  0.0895146 phase:  0.0254538°          voltage
V(n004):       mag:  0.0940863 phase:  0.0254538°          voltage
V(vo):         mag:  0.0940859 phase:   0.167839°          voltage
V(n003):       mag:  0.0950528 phase: 0.000875256°         voltage
V(n002):       mag:        0.1 phase:          0°          voltage
Ic(Q1):        mag: 4.74152e-005 phase:  0.0659414°        device_current
Ib(Q1):        mag: 4.74152e-007 phase:  0.0659414°        device_current
Ie(Q1):        mag: 4.78894e-005 phase:   -179.934°        device_current
I(C3):         mag: 6.96364e-006 phase:  0.0312136°        device_current
I(Cc1):        mag: 4.94716e-007 phase:    179.983°        device_current
I(Cc2):        mag: 1.68011e-005 phase:   -179.832°        device_current
I(R3):         mag: 2.05761e-008 phase:   -1.92423°        device_current
I(Rs):         mag: 4.94716e-007 phase:    179.983°        device_current
I(Rl):         mag: 1.68011e-005 phase:   -179.832°        device_current
I(Re):         mag: 2.41247e-005 phase: 0.00500168°        device_current
I(R2):         mag: 2.41247e-006 phase:  0.0254538°        device_current
I(Rpot):       mag: 4.57174e-006 phase:   -179.975°        device_current
I(R1):         mag: 4.57174e-006 phase:   -179.975°        device_current
I(Vcc):        mag: 4.28435e-005 phase:    -179.93°        device_current
I(Vs):         mag: 4.94716e-007 phase:    179.983°        device_current
```

**Other parameters:**

Vin = 0.0950528 V ∡ 0.00562132°
Iin = 0.494716 µA ∡ 179.983°
Vout = 0.0940859 V ∡ 0.167839°
Iout = 16.8011 µA ∡ -179.832°

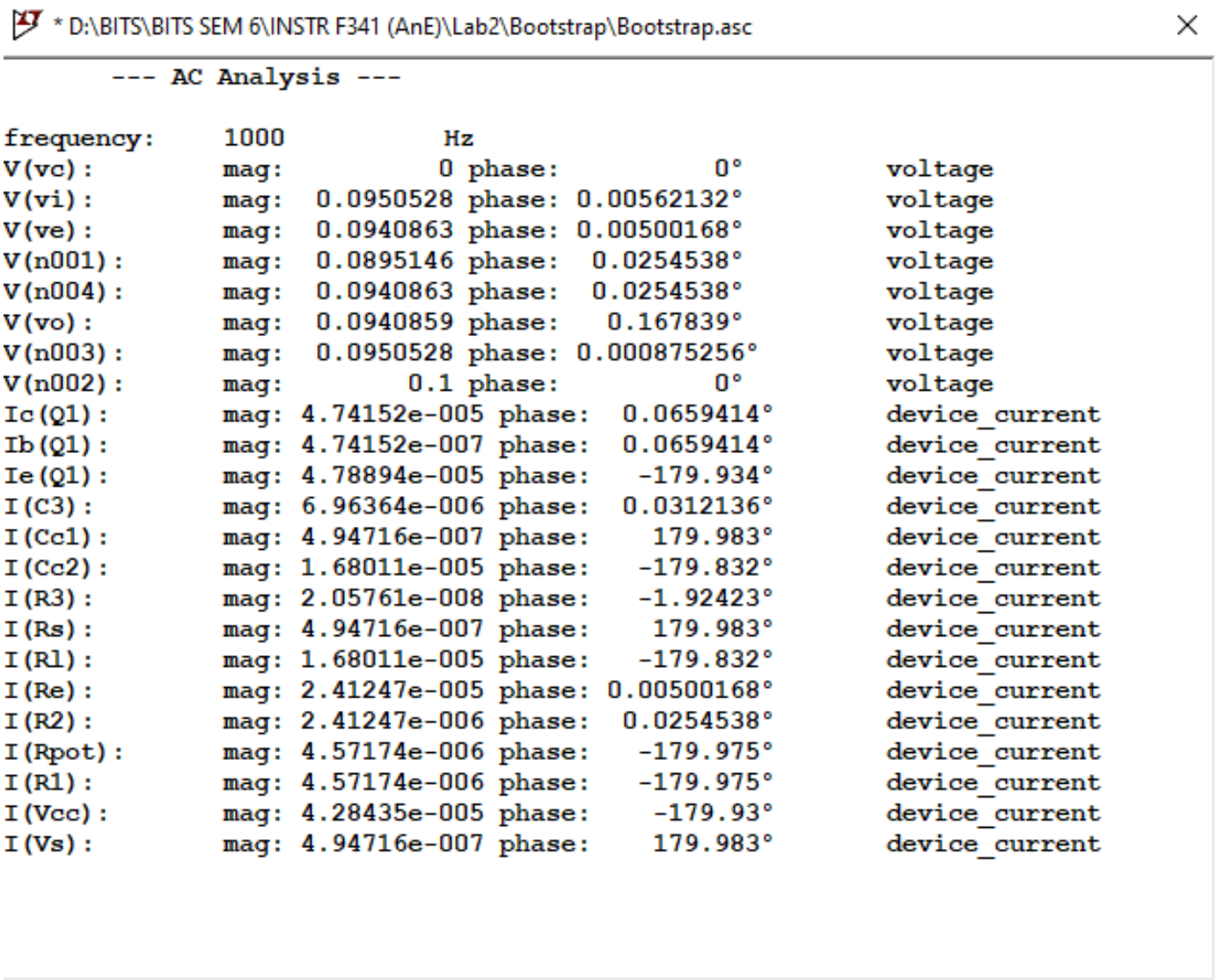
# Input and Output waveforms
# (.tran 10m)



# Input resistance ($R_{in}$)

**DC input resistance**: infinite (as input capacitor blocks all dc voltage)

**AC input resistance**:

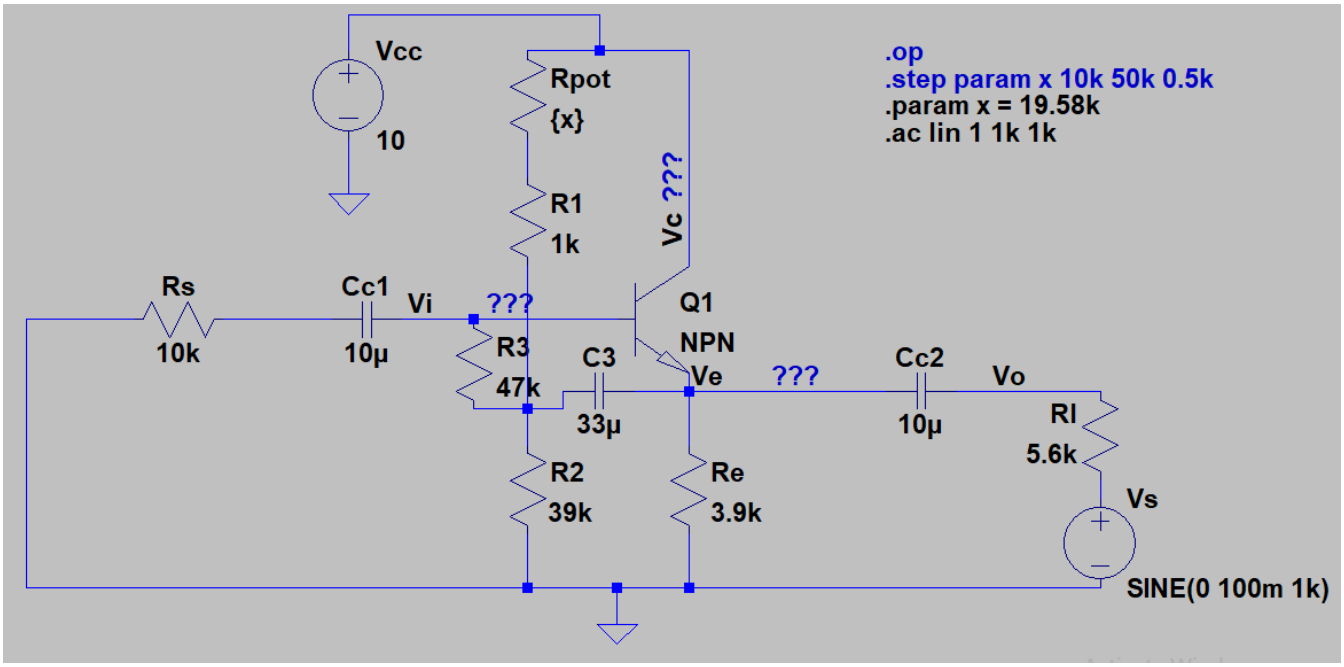


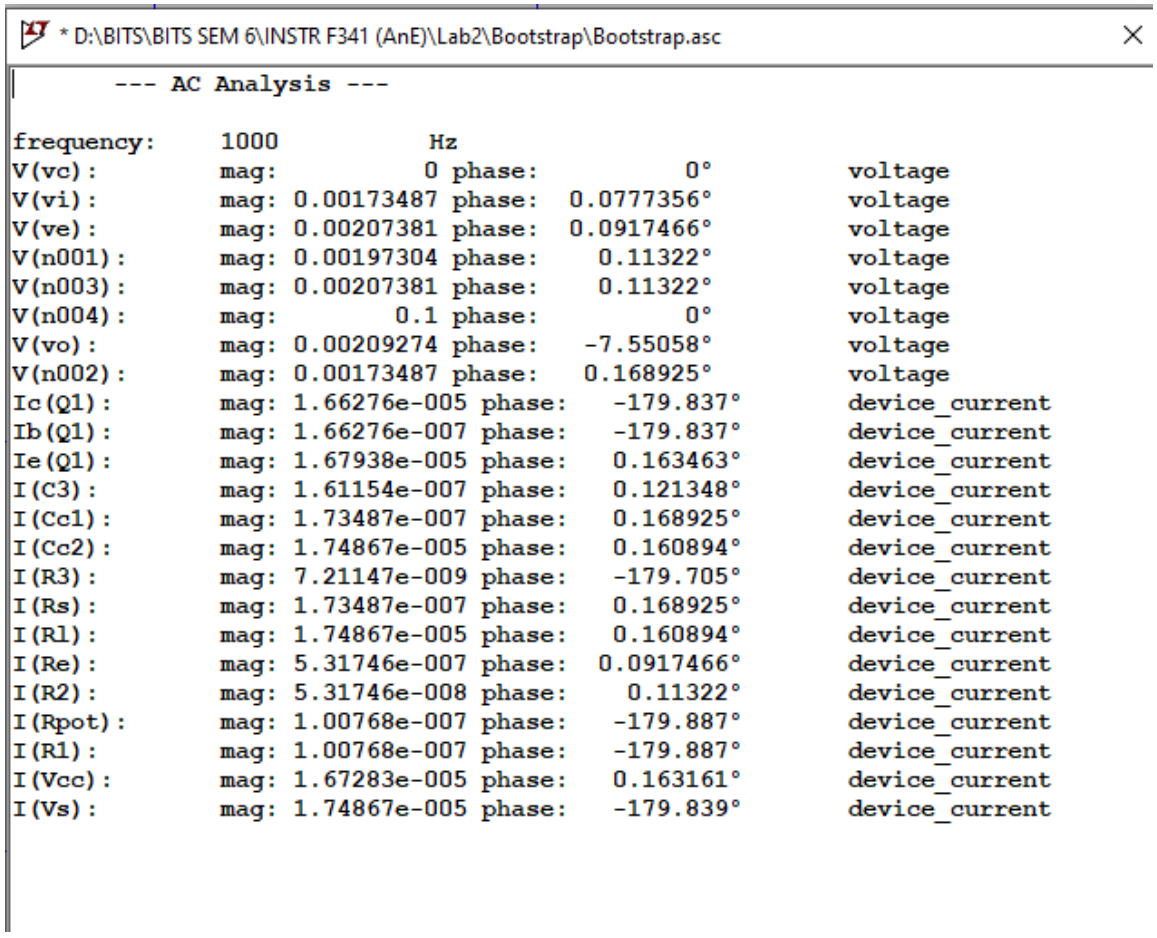

$$R_{in} = \frac{V_{in}}{I_{in}} = \frac{V(vi)}{I(Vs)} = \frac{0.0950528}{4.94716 \times 10^{-7}} = 192.136\ k\Omega$$

# Output resistance ($R_{out}$)

**DC output resistance**: 5.6 kΩ

**AC output resistance**:



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```
      --- AC Analysis ---

frequency:     1000          Hz
V(vc):         mag:           0 phase:          0°          voltage
V(vi):         mag: 0.00173487 phase:  0.0777356°          voltage
V(ve):         mag: 0.00207381 phase:  0.0917466°          voltage
V(n001):       mag: 0.00197304 phase:    0.11322°          voltage
V(n003):       mag: 0.00207381 phase:    0.11322°          voltage
V(n004):       mag:         0.1 phase:          0°          voltage
V(vo):         mag: 0.00209274 phase:   -7.55058°          voltage
V(n002):       mag: 0.00173487 phase:   0.168925°          voltage
Ic(Q1):        mag: 1.66276e-005 phase:   -179.837°        device_current
Ib(Q1):        mag: 1.66276e-007 phase:   -179.837°        device_current
Ie(Q1):        mag: 1.67938e-005 phase:   0.163463°        device_current
I(C3):         mag: 1.61154e-007 phase:   0.121348°        device_current
I(Cc1):        mag: 1.73487e-007 phase:   0.168925°        device_current
I(Cc2):        mag: 1.74867e-005 phase:   0.160894°        device_current
I(R3):         mag: 7.21147e-009 phase:   -179.705°        device_current
I(Rs):         mag: 1.73487e-007 phase:   0.168925°        device_current
I(Rl):         mag: 1.74867e-005 phase:   0.160894°        device_current
I(Re):         mag: 5.31746e-007 phase:  0.0917466°        device_current
I(R2):         mag: 5.31746e-008 phase:    0.11322°        device_current
I(Rpot):       mag: 1.00768e-007 phase:   -179.887°        device_current
I(R1):         mag: 1.00768e-007 phase:   -179.887°        device_current
I(Vcc):        mag: 1.67283e-005 phase:   0.163161°        device_current
I(Vs):         mag: 1.74867e-005 phase:   -179.839°        device_current
```

$$R_{out} = \frac{V_{out}}{I_{out}} = \frac{V(vo)}{I(Vs)} = \frac{0.00209274}{1.74867 \times 10^{-5}} = 119.676\ \Omega$$

## Observations and Conclusions

1. The common collector configuration approximately gives the same amplitude of output waveform as the input waveform, shifted by a DC offset. Hence, it is also called emitter follower and acts as level shifter.
2. The main advantage of Darlington pair over Common collector topology is that it gives a higher current gain because of cascading of two BJTs, which multiplies their $h_{FE}$ (or β-value).
3. Bootstrap configuration is used to get high input impedance as the input impedance of the other two configurations contribute to loading effects which can be seen in their waveforms (120 mV peak-to-peak). The Bootstrap configuration however has a much higher input resistance and gives nearly the same waveform as the source voltage (gives 190 mV peak-to-peak while source has 200 mV peak-to-peak).
4. The output resistance of all the three configurations is low which is a desired characteristic of an amplifier.
5. The purpose of all the three amplifiers is to shift the DC offset of input while keeping the amplitude same at input and output terminals.
6. The best amplifier for voltage level shift is the bootstrap configuration since the source voltage is least attenuated due to loading at BJT input.
7. The best amplifier for high current gain is Darlington configuration due to two cascaded BJTs.