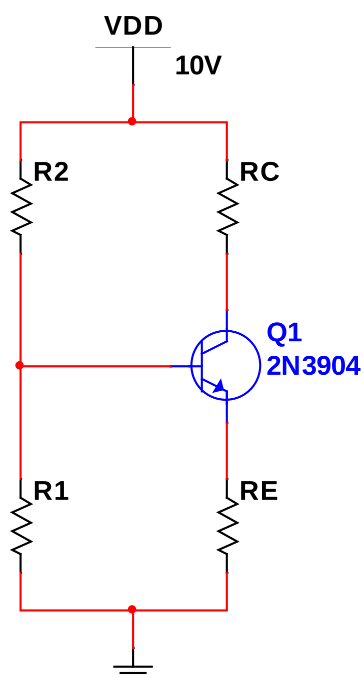
BEE 332 Devices and circuits II
Spring 2017
Lab 2: Single-stage BJT amplifiers instructor's notes[*]

3.2 Measurements

3.2.1 Establish the base voltage

You are asked to pick values for R1, R2, RE and RC for the following circuit.



R1 and R2 are to be chosen to give VB ≃ 1.5 V and about 150 μA through the divider.

$$VB = 1.5 = VDD * \left(\frac{R1}{R1 + R2}\right) = 10 * \left(\frac{R1}{R1 + R2}\right)$$

$$\frac{R1}{R1 + R2} = 0.15$$

$$I = 150\ \mu A = \frac{VDD}{R1 + R2} = \frac{10}{R1 + R2}$$

$$R1 + R2 = \frac{10}{150 \times 10^{-6}}$$

$$R1 = 66.7K - R2$$

$$\frac{66.7K - R2}{66.7K - R2 + R2} = 0.15$$

$$1 - \frac{R2}{66.7K} = 0.15$$

$$R2 = (1 - 0.15) * 66.7K = 56.7K$$

$$R1 = 66.7K - R2 = 10K$$

Since you do not have these values in your kit, you had to decide what to do instead. What you should have realized is that all that mattered was that the bias voltage should be about 1.5V and that the current should be large compared to the expected IB, meaning you could choose smaller resistors you did have that maintained roughly the same ratio.

$$Ratio = \frac{56.7K}{10K} = 5.67$$

[*] These notes were written by Nicole Hamilton.

Choosing R1 = 6.8K and R2 = 43K is close enough.

$$Ratio = \frac{43K}{6.8K} = 6.3$$

$$Expected\ VB = 10 * \left(\frac{6.8K}{43K + 6.8K}\right) = 1.37V$$

3.2.2 Choose RE

Pick a value for RE so that if IRE = 0.8 mA for VRE = 0.8 V.

$$RE = \frac{0.8\ V}{0.8\ mA} = 1K$$

3.2.3 Choose RC

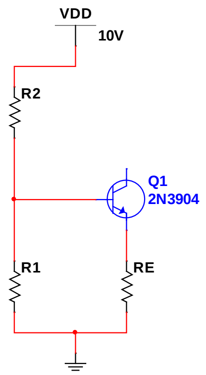
Assume IE ≃ IC ≃ 0.8 mA. Choose RC to set VC ≃ 6 V.

$$RC = \frac{VDD - VC}{0.8\ mA} = 5K$$

Measured values:

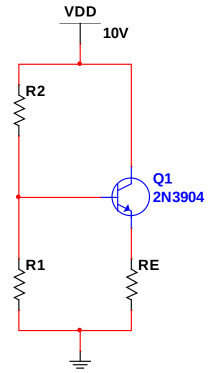
R1 = 6.68 K
R2 = 42.4 K
RC = 5.03 K
RE = 983 Ω
VDD = 10.1 V

You were then asked to make take measurements as you made changes to the circuit. Shown here are my measurements, likely typical.



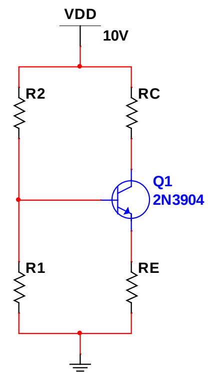
Collector not connected.

VB = 0.7367 V
VE = 0.1094 V



Collector wired to VDD.

VB = 1.344 V
VE = 0.7088 V



RC added.

VB = 1.344 V
VE = 0.7096 V
VC = 6.540 V

3.3 Questions

1. From measured values of VE, VB and VC, calculate each current.

$$IE = \frac{VE}{RE} = \frac{0.7096}{983} = 722\ \mu A$$

$$IC = \frac{VDD - VC}{RC} = \frac{10.1 - 6.540}{5.03\ K} = 708\ \mu A$$

$$IB = IR2 - IR1 = \frac{VDD - VB}{R2} - \frac{VB}{R1} = \frac{10.1 - 1.344}{42.4\ K} - \frac{1.344}{6.68\ K} = 5.31\ \mu A$$

2. Verify that KCL for Q1.

$$IB = IE - IC = 14.1\ \mu A$$

Calculated IB is too small, likely due to measurement imprecision on the divider.

3. Calculate β.

$$\beta \le \frac{722\ \mu A}{5.31\ \mu A} = 136\ and\ \beta \ge \frac{722\ \mu A}{14.1\ \mu A} = 51$$

4. For an NPN in forward active, order VE, VB and VC in increasing voltage.

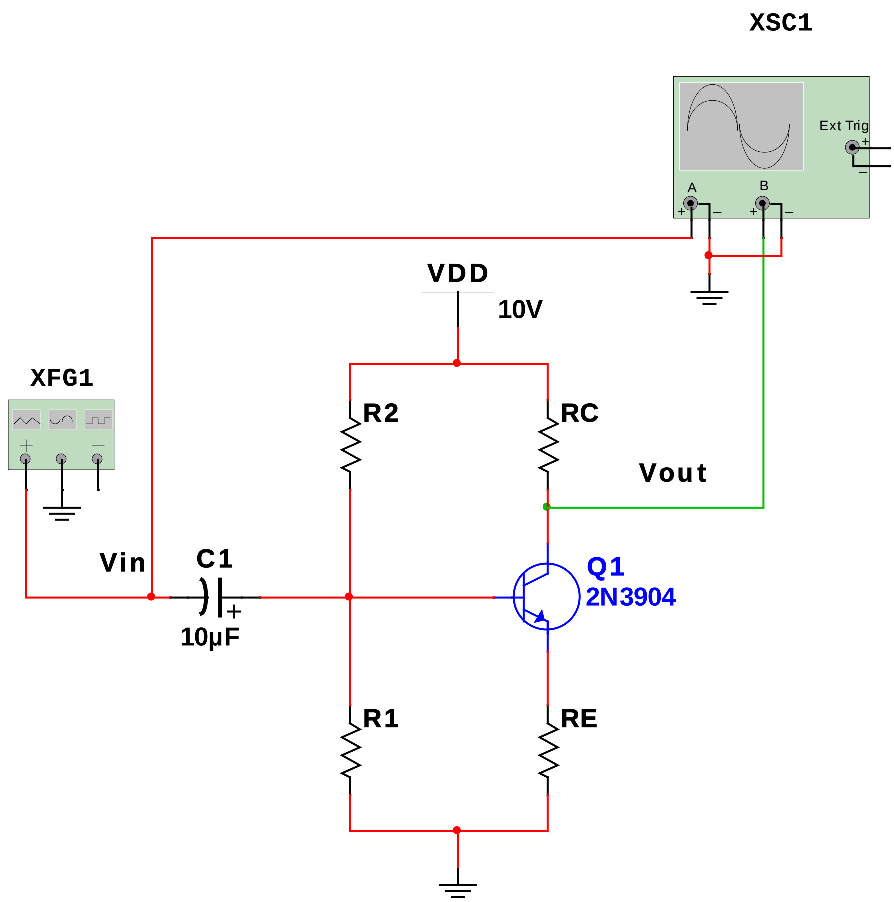
   VE < VB < VC

5. Do it again, ordering VE, VB and VC for a PNP.

   VC < VB < VE

4 Common emitter amplifier

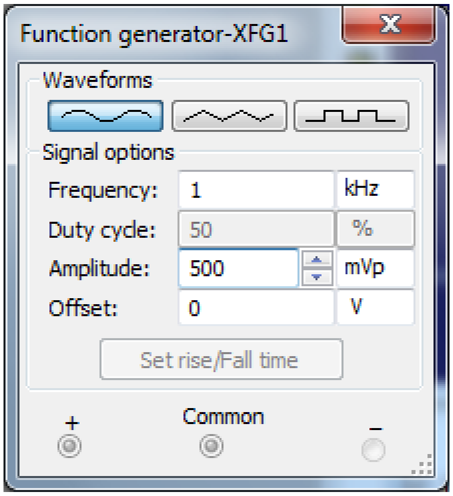
You were asked to simulate and measure the following circuit and paste a copy of your schematic into your report. Values shown are as calculated in section 3. Vin = 1.0 Vpp sine wave @ 1 KHz. Shown are my actual results, probably typical.

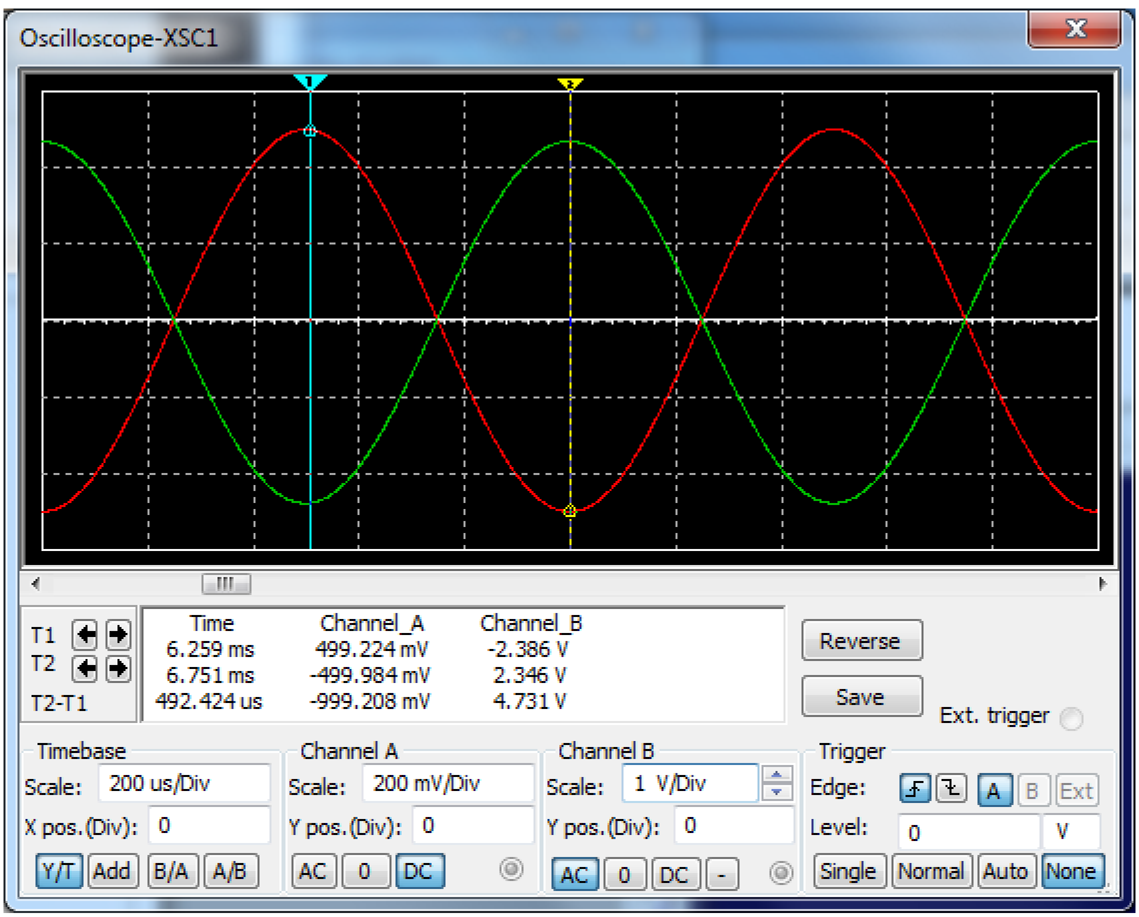


4.1 Simulation

4.1.1 Gain

1. Screenshot with Vin = 1.0 Vpp sine wave at 1.0 kHz. The result is an inverting amplifier.





2. Calculate Av.

$$Av = \frac{-4.733}{1.00} = -4.73$$

Notice that the output has a DC bias, roughly matching the Q-point VC measured previously

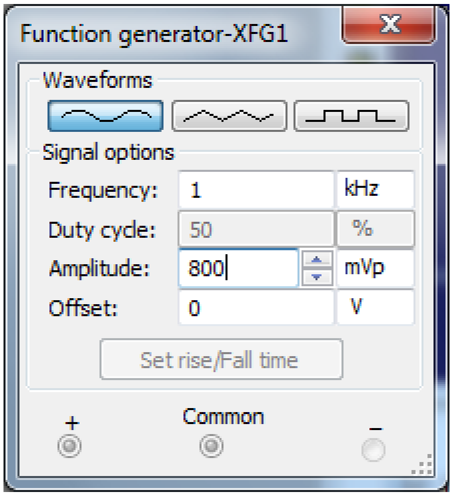
$$Vout_{min} = 4.215\ V$$

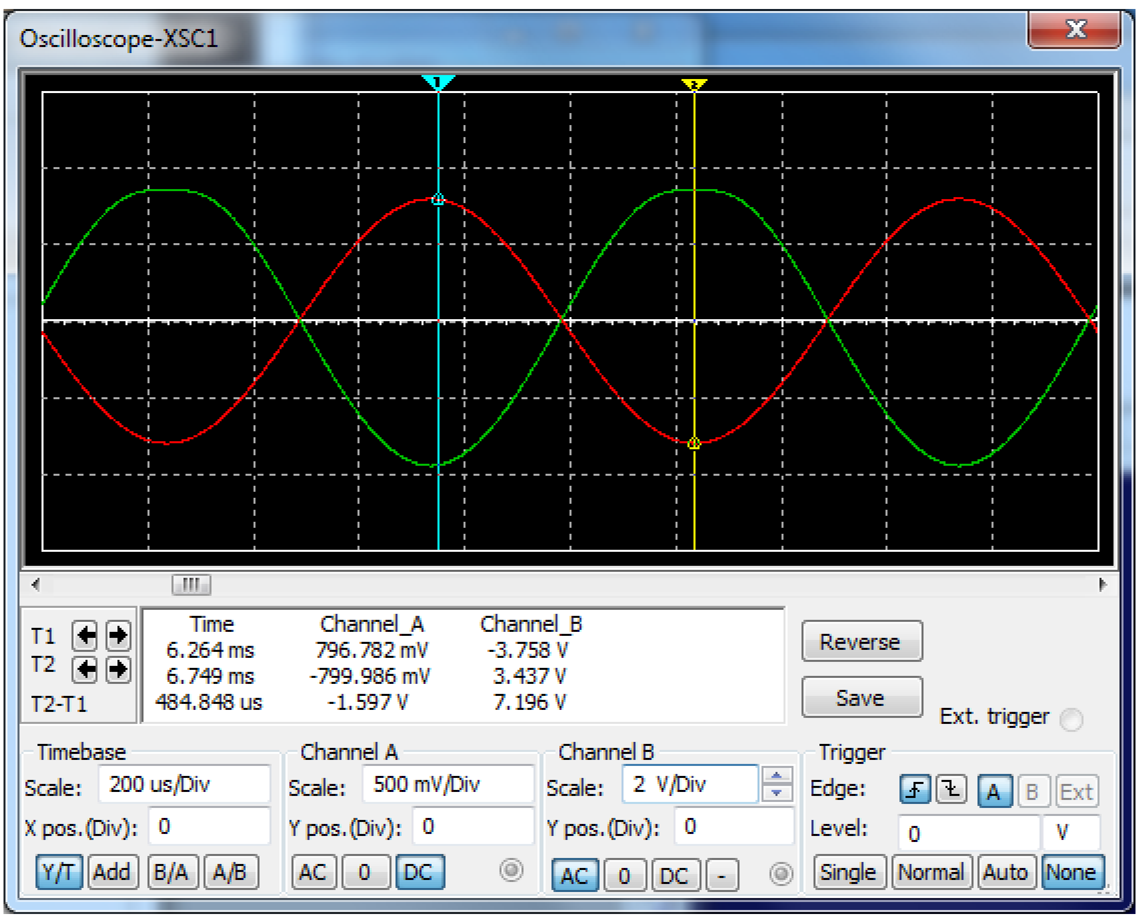
$$Vout_{max} = 8.948\ V$$

$$Vout_{midpoint} == \frac{8.948 + 4.215}{2} = 6.58\ V$$

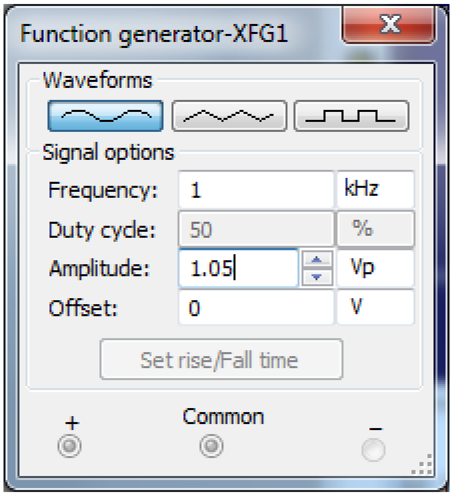
4.1.2 Clipping

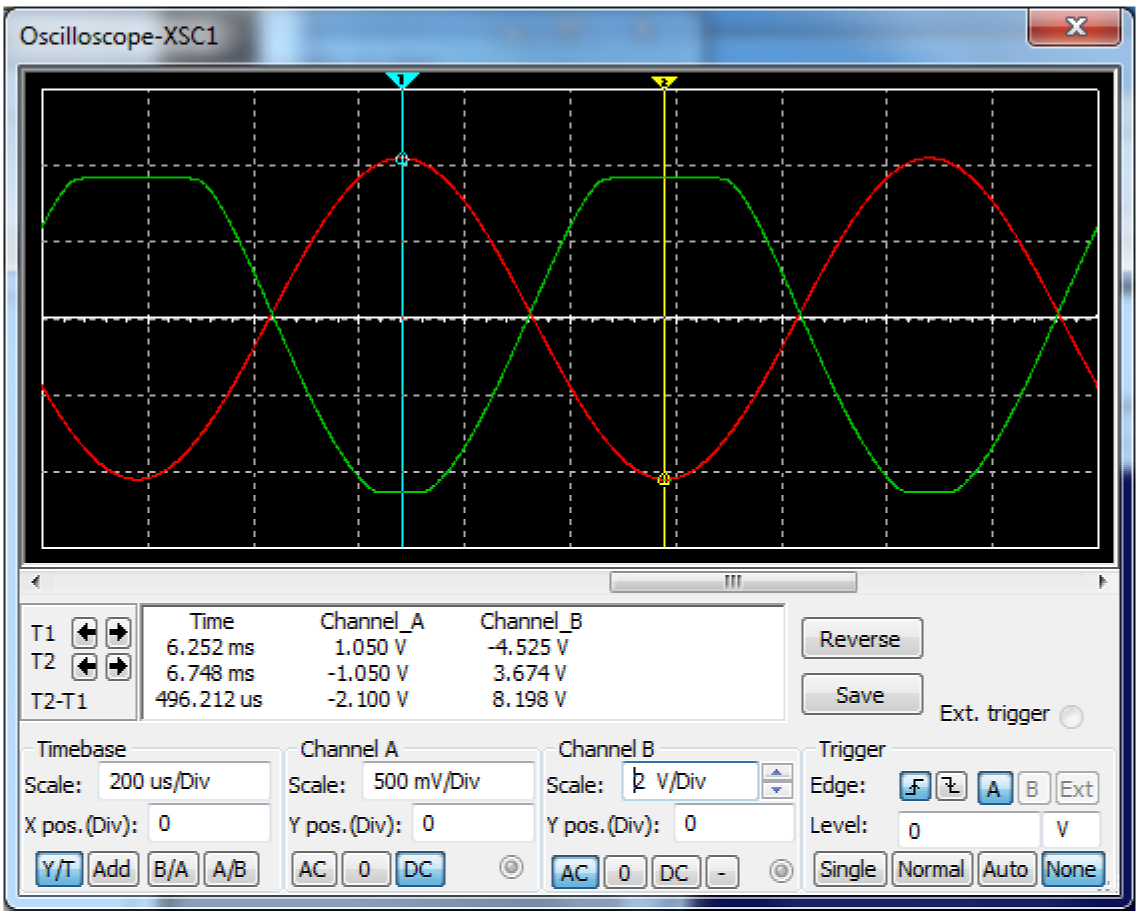
3. Clipping on one peak happens at Vin = 800 mVp = 1.6 Vpp, Vout = 7.196 Vpp when the transistor turns off as VB drops too low to keep VBE above the .7 V turnon voltage. Clipping is rounded because there's a rounded knee in the transistor IC curve.





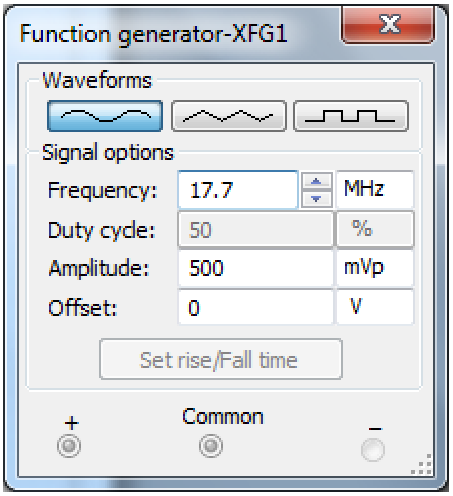
4. Clipping at the bottom happens when the transistor saturates with Vin = 1.05 Vp = 2.1 Vpp, Vout = 8.198 Vpp.



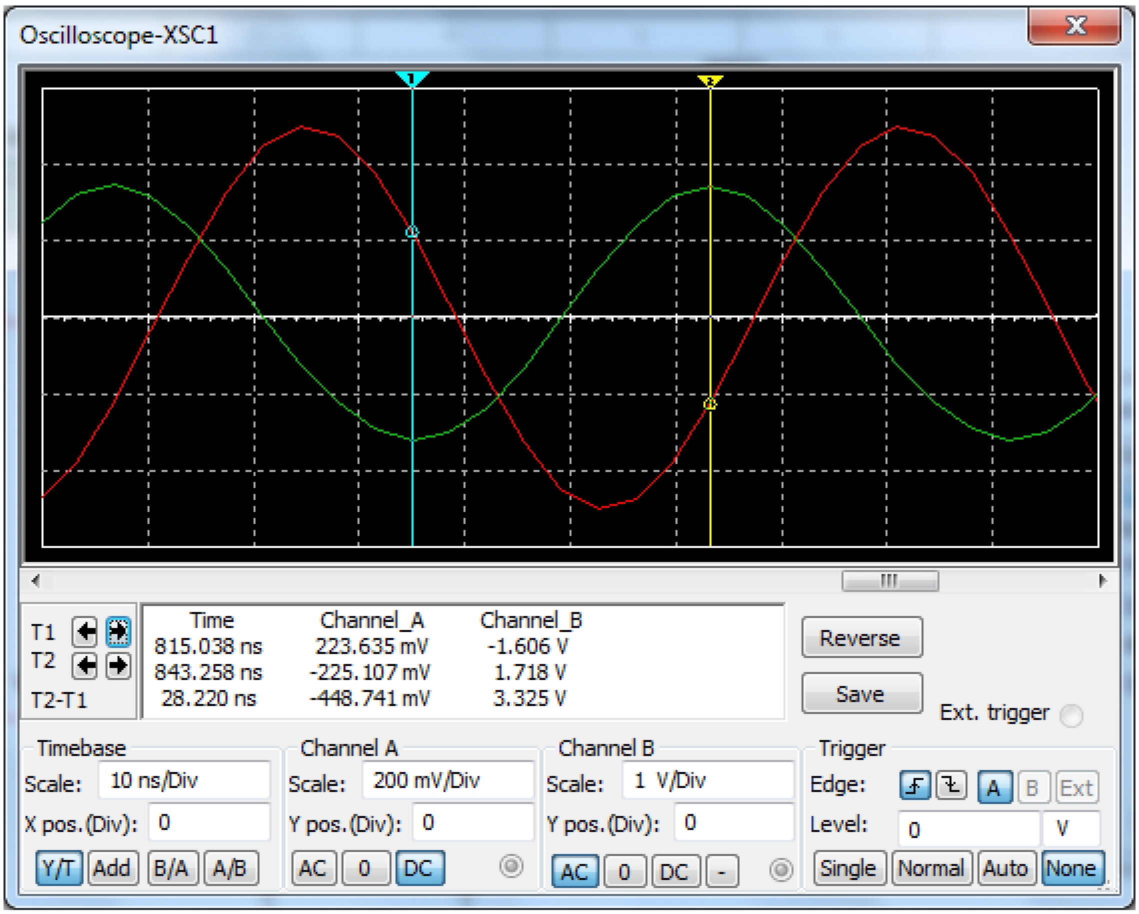


4.1.3 Bandwidth

5. Av = -4.73 at 1 KHz. The 3 dB point is where Av = .707 * (-4.73) = 3.345. In simulation, this is reached at roughly 17.7 MHz, where Av = Vin/Vout = -3.325/.997 = -3.335.



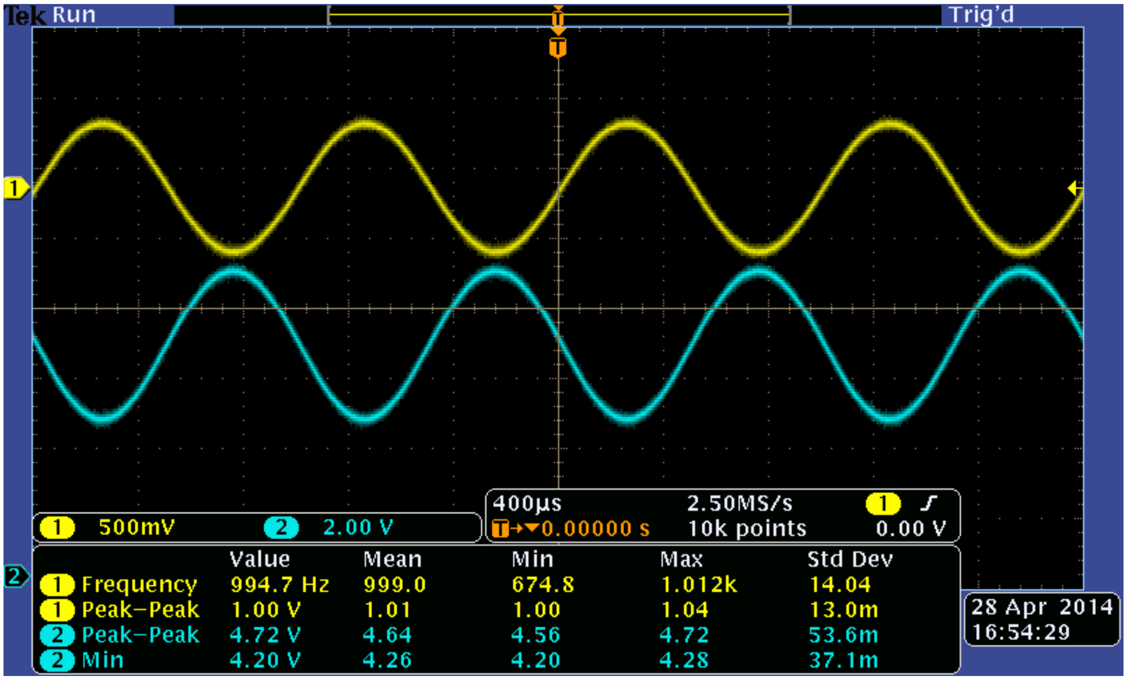
Shown here, Vout = 3.325 Vpp.



4.3 Measurements

4.3.1 Gain

1. Screenshot of Vin and Vout with Vin = 1.0 Vpp sine wave at 1.0 KHz. This screenshot was taken with DC coupling to measure the DC offset in Vout.



2. Calculate gain.

$$Av = \frac{-4.72}{1.00} = -4.72$$

Note that midpoint of Vout is the VC Q-point measured previously.

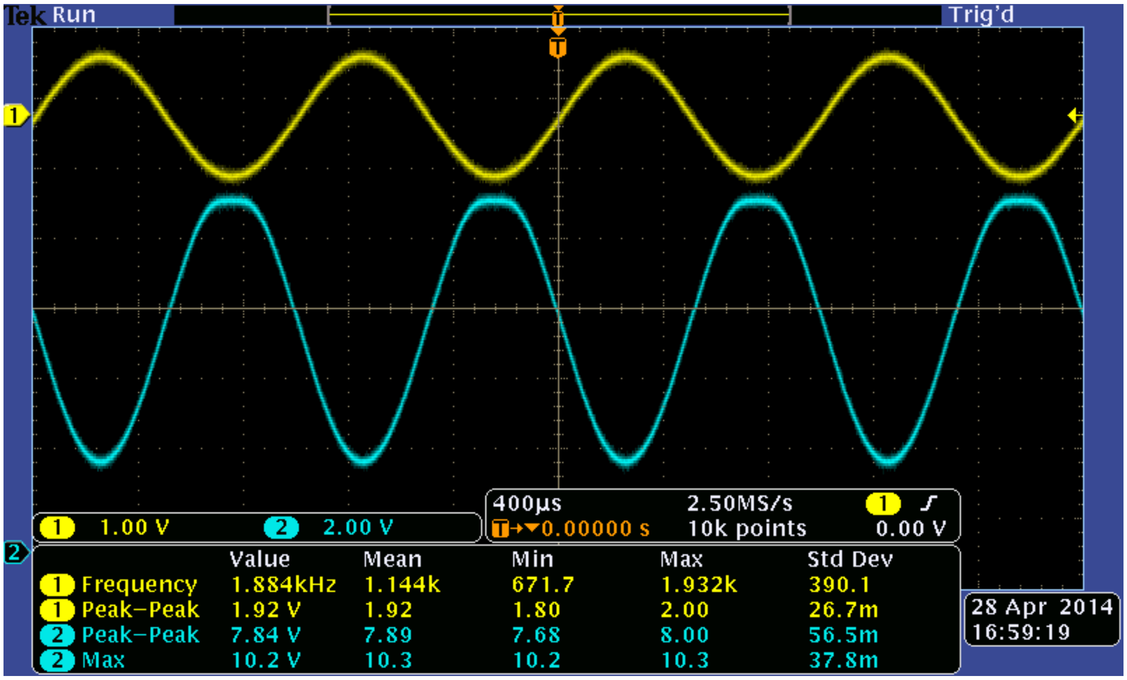
$$Vout_{min} = 4.2\ V$$

$$Vout_{max} = 4.2 + 4.7 = 8.72\ V$$

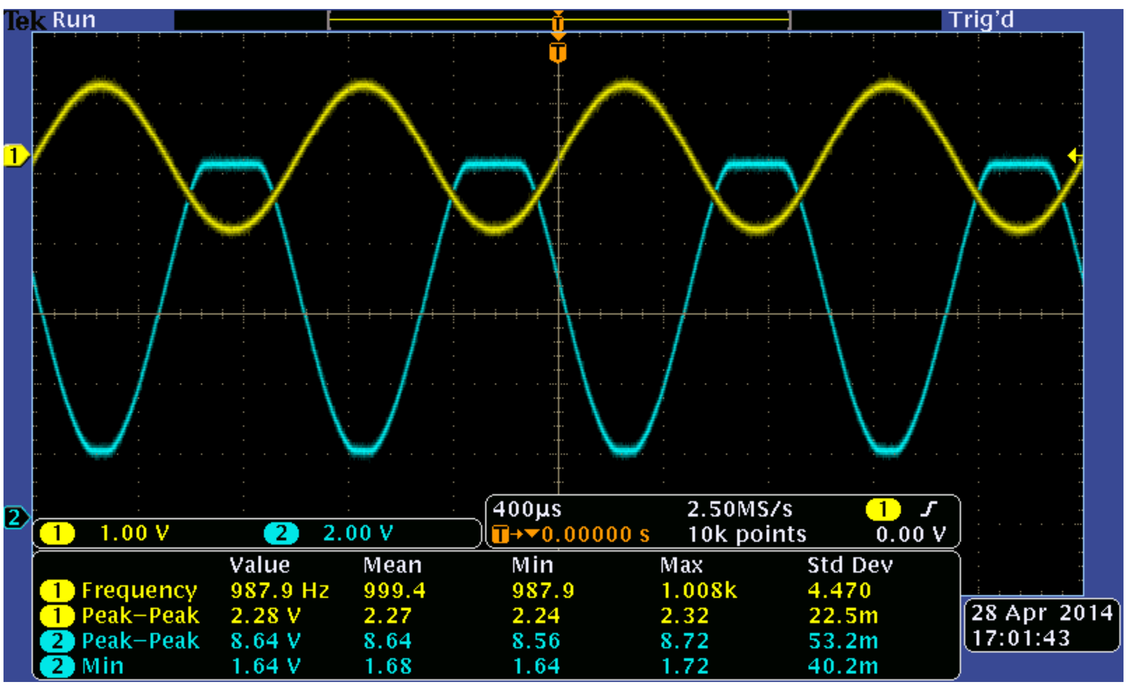
$$Vout_{midpoint} = 4.2 + \frac{4.7}{2} = 6.56\ V$$

4.3.2 Clipping

4. Increase Vin until Vout begins to clip on one peak. Vin = 1.92 Vpp, Vout = 7.89 Vpp.

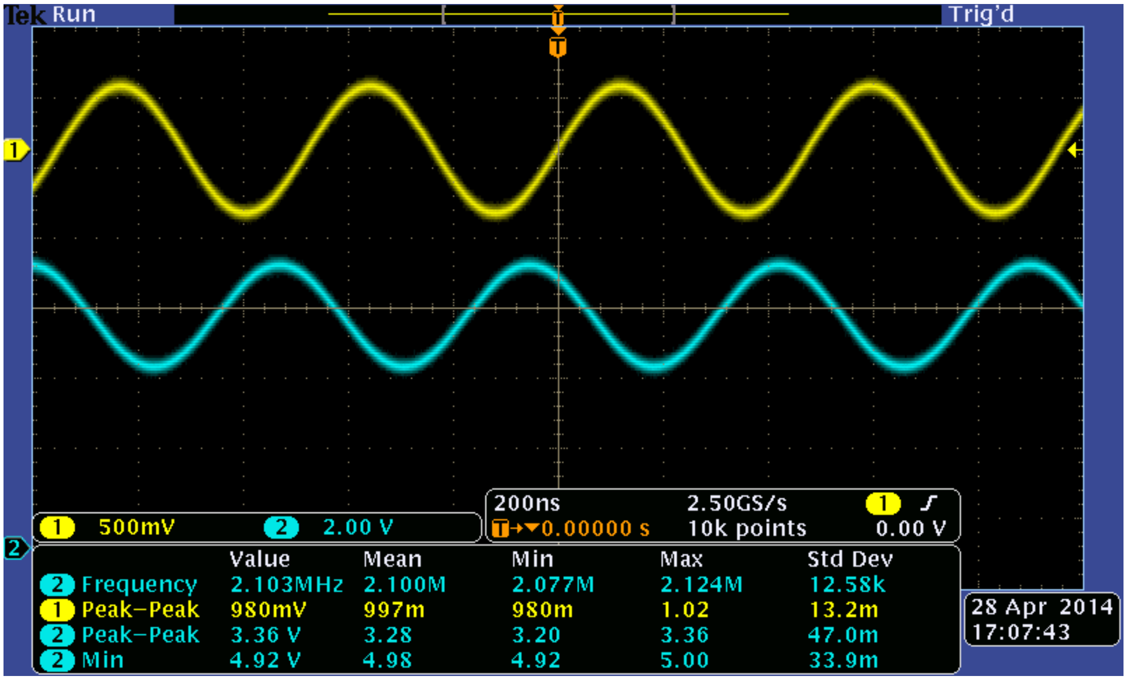


5. Increase Vin until Vout clips both peaks. Vin = 2.27 Vpp, Vout = 8.64 Vpp.



4.3.3 Bandwidth

7. Decrease amplitude output is a pure sine wave, then find frequency at which Av falls 3 db to .707 * (-4.72) = -3.34. Shown here, Av = -3.36 V / 980 mv = 3.42 at 2.1 MHz.



4.4 Questions

1. Is this amplifier inverting or non-inverting?

   Inverting.

2. Suggest a redesign to avoid upper clipping.

   This amplifier is inverting, meaning the output clips at the top when the input is at the bottom. Upper clipping is happening when the transistor is switching off because Vin is below 0.7V. If it's just a matter of "centering" the bias point, VB can be raised slightly by lowering R2 or increasing R1. In simulation, changing R2 from 43K to 40K caused upper clipping disappeared for Vin = 1.916Vpp.

   Another alternative is to increase VDD, e.g., from 10V to 12V, which also increases VB by the proportion of the divider, and also helps on lower clipping, discussed below. No surprise, because this is about Vin going too low and the transistor shutting off, changing RC or RE doesn't really help.

3. Suggest a redesign to avoid lower clipping.

   Lower clipping is happening when the transistor is saturated, meaning it can no longer drop VCE any further and remain in the forward active region. It can no longer maintain the IC = β * IB relationship. If it's just a matter of "centering" the bias point, the bias VB can be lowered slightly by increasing R2 or lowering R1. Through simulation, I found that lower clipping was eliminated at about R2 = 50K with VDD still at 10V though at this point, upper clipping was quite severe, so this was not a solution here.

Because saturation is fundamentally an output condition, a better strategy is to increase VDD or lower RC and RE, reducing the IR drops across these resistors. Leaving R2 = 43K, but either (a) raising VDD to 12V or (b) changing RC and RE to 4KΩ and 800Ω, respectively, eliminated all visible clipping at Vin = 2.28Vpp.

4. When coupled through C1, what is the DC voltage gain?

   Zero.

5. What is the function of C1?

   Passes AC only, blocking DC. This is useful because the base of Q1 is biased to a non-zero value but input signals are more likely to have no DC component.

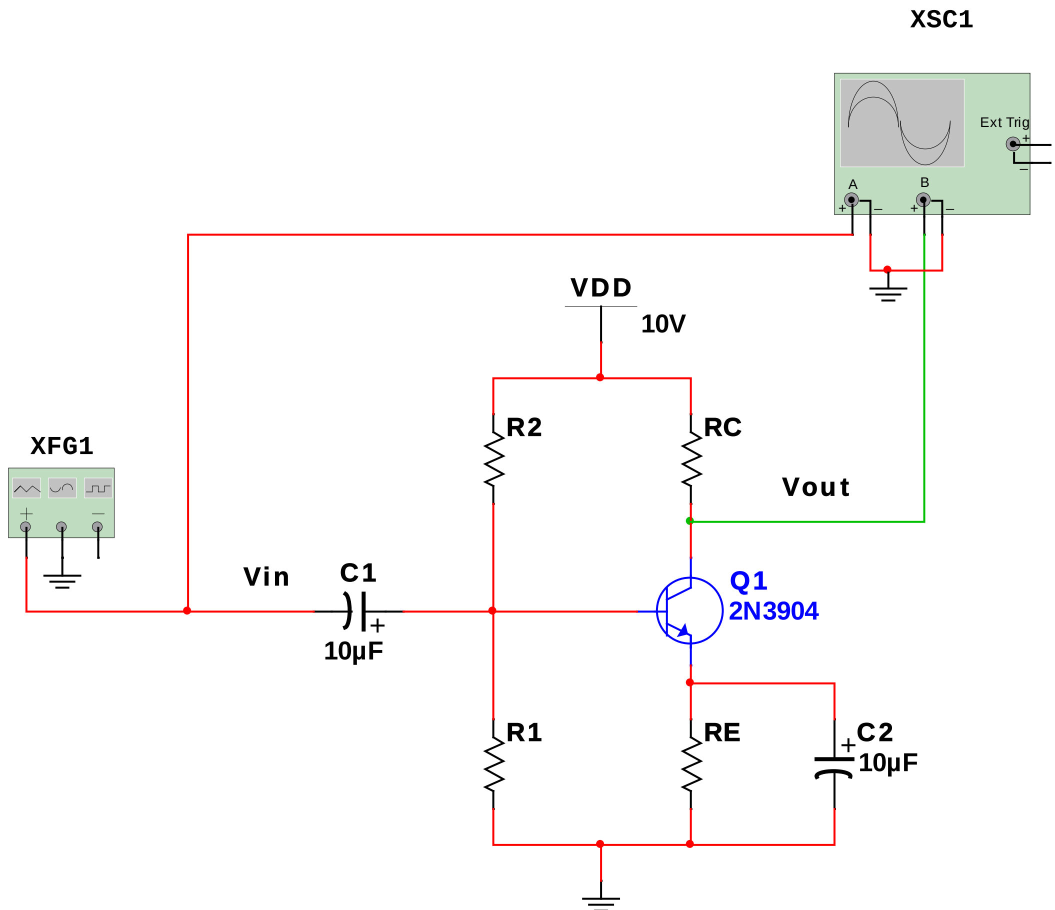
6. Do your measured results agree with your simulation?

   Yes, for everything except bandwidth, which measured much lower than predicted by simulation. (Simulations of transistor circuits are often optimistic.)

Parameter	Simulated	Measured
Av	-4.73	-4.72
Vin onset of clipping	1.6 Vpp	1.92 Vpp
Vin clipping both peaks	2.1 Vpp	2.27 Vpp
3 dB point	17.7 MHz	2.1 MHz

5 Common emitter with bypassed emitter resistor

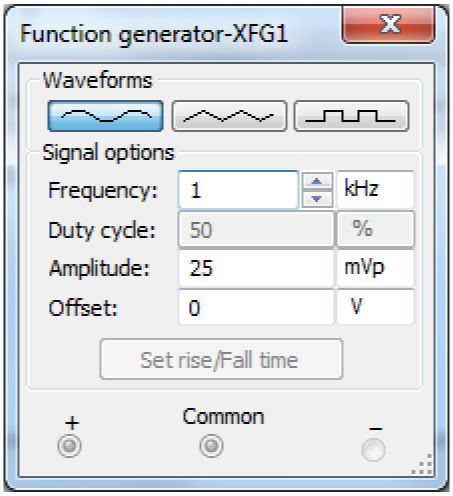
You were asked to simulate and take measurements of this circuit.
Initially Vin =50 mVpp sine wave @ 1 KHz.

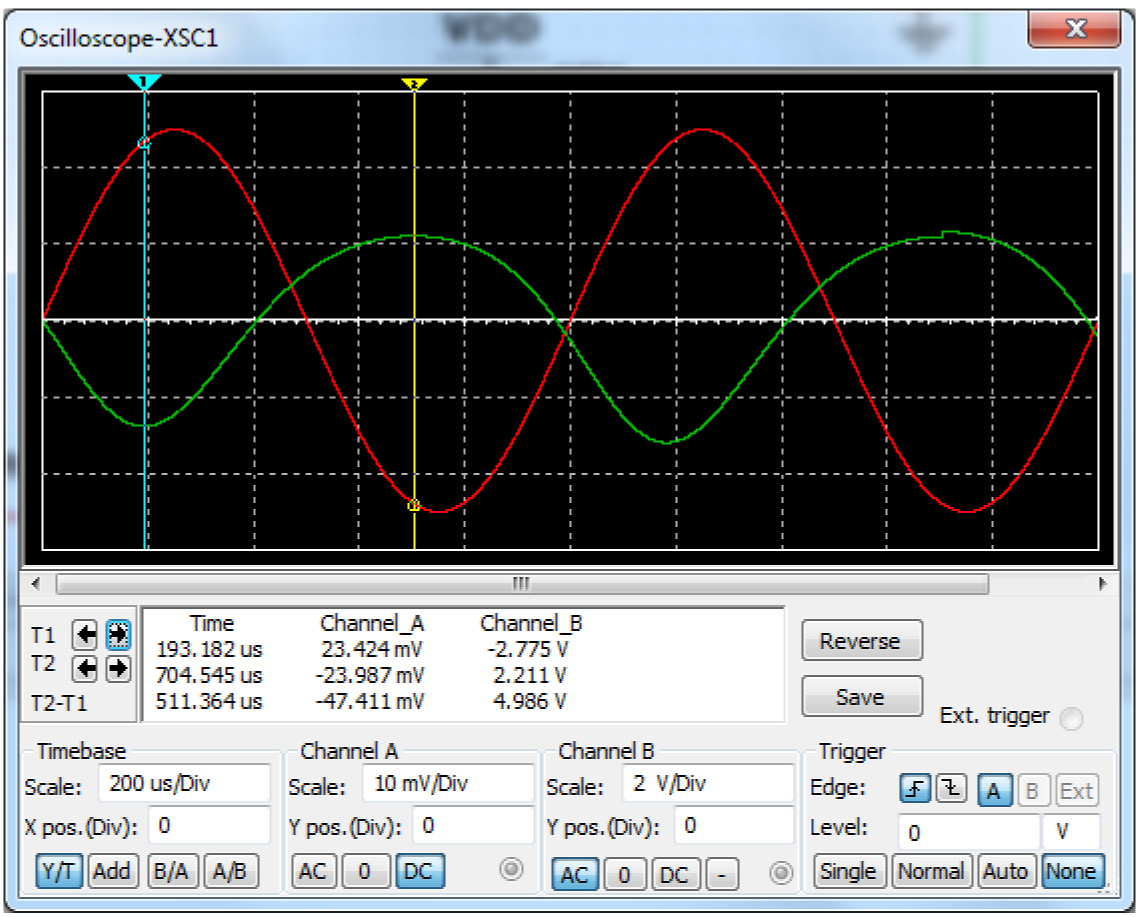


5.1 Simulation

5.1.1 Gain

1. Screenshot of Vin and Vout with Vin = 50 mVpp at 1.0 KHz.

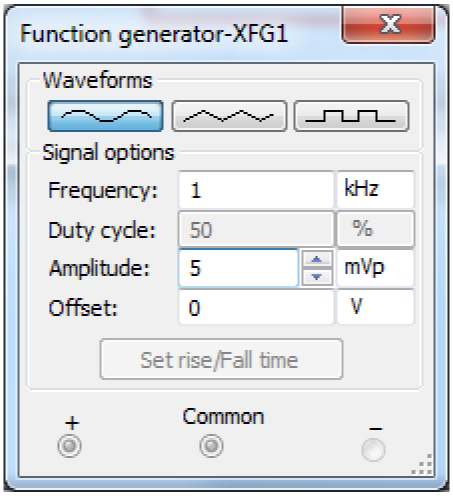


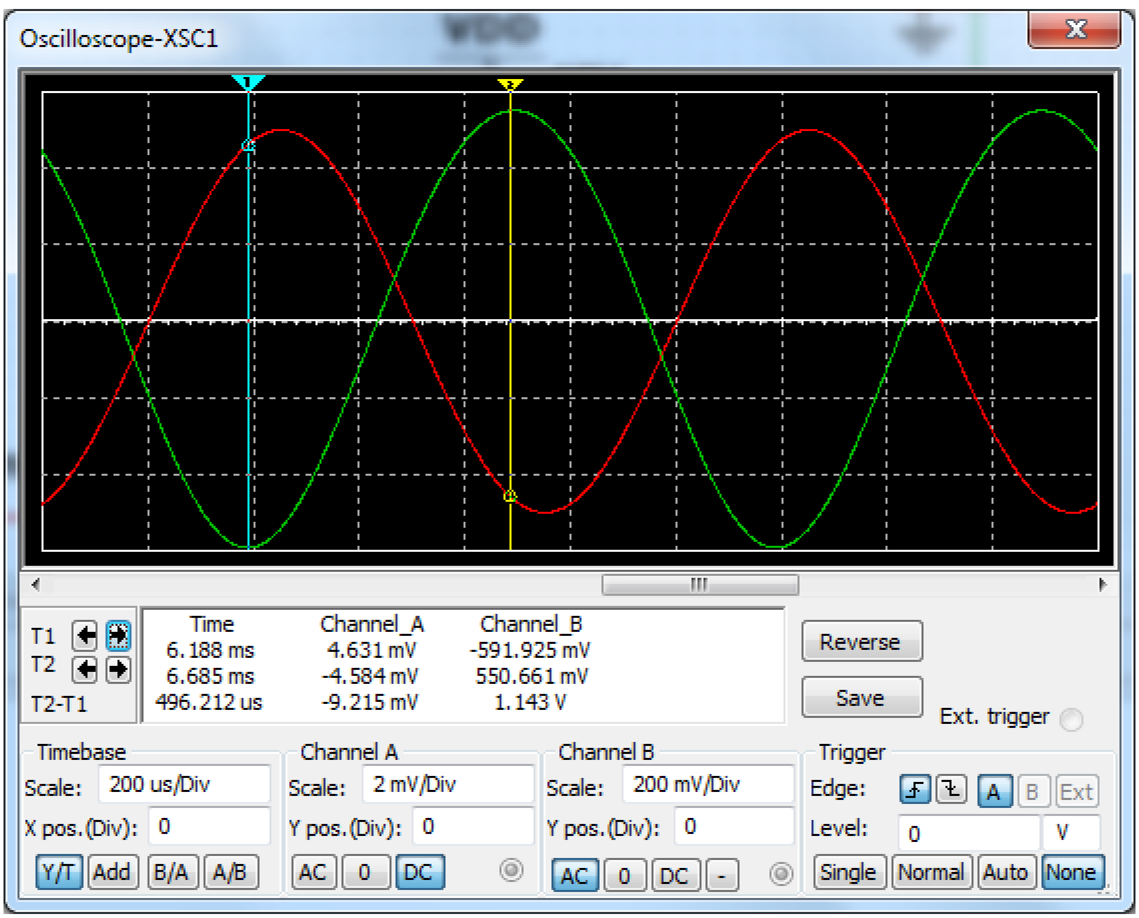


2. Simulation predicts Av = -4.986 Vpp / 50 mVpp = -99.7. But note the severe distortion.

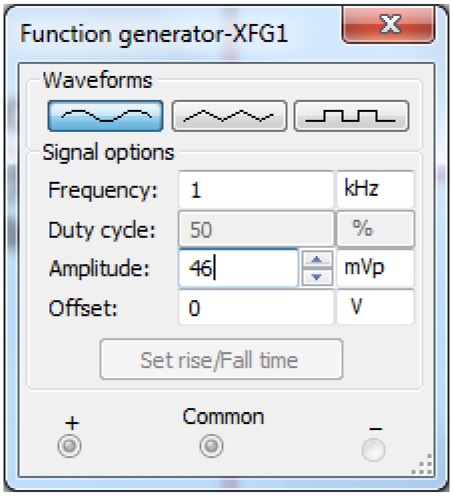
5.1.2 Clipping

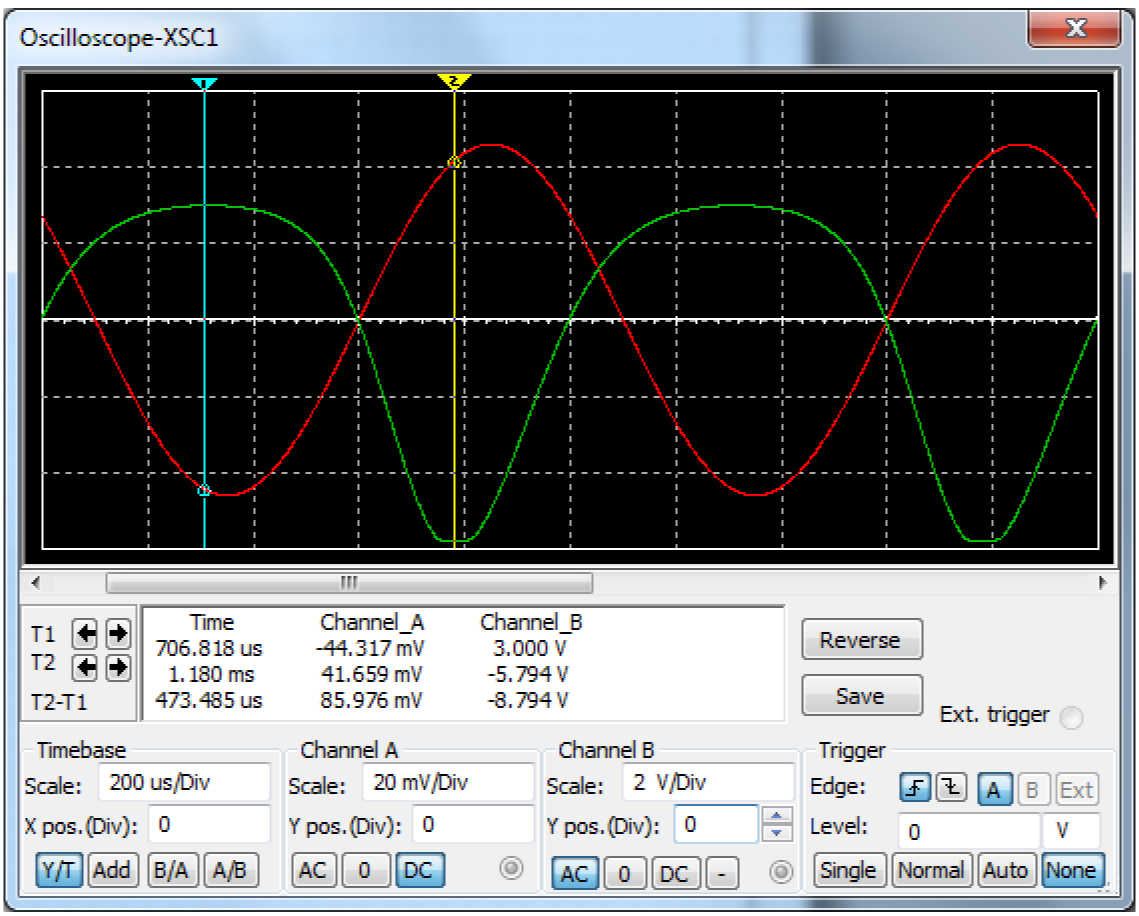
3. Vout is already clipping at Vin = 50 mVpp. To get a clean output, I had to reduce Vin to 5 mVp = 10 mVpp, in the range discussed as in roughly the small signal range for vbe. Shown here, Vout = 1.143 Vpp, Av = Vout / Vin = - 114.3.





4. Clipping at both peaks occurs at Viin = 46 mVp = 92 mVpp, Vout = 8.794 Vpp.

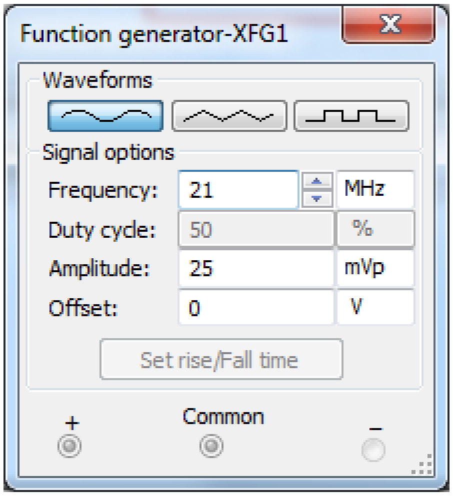


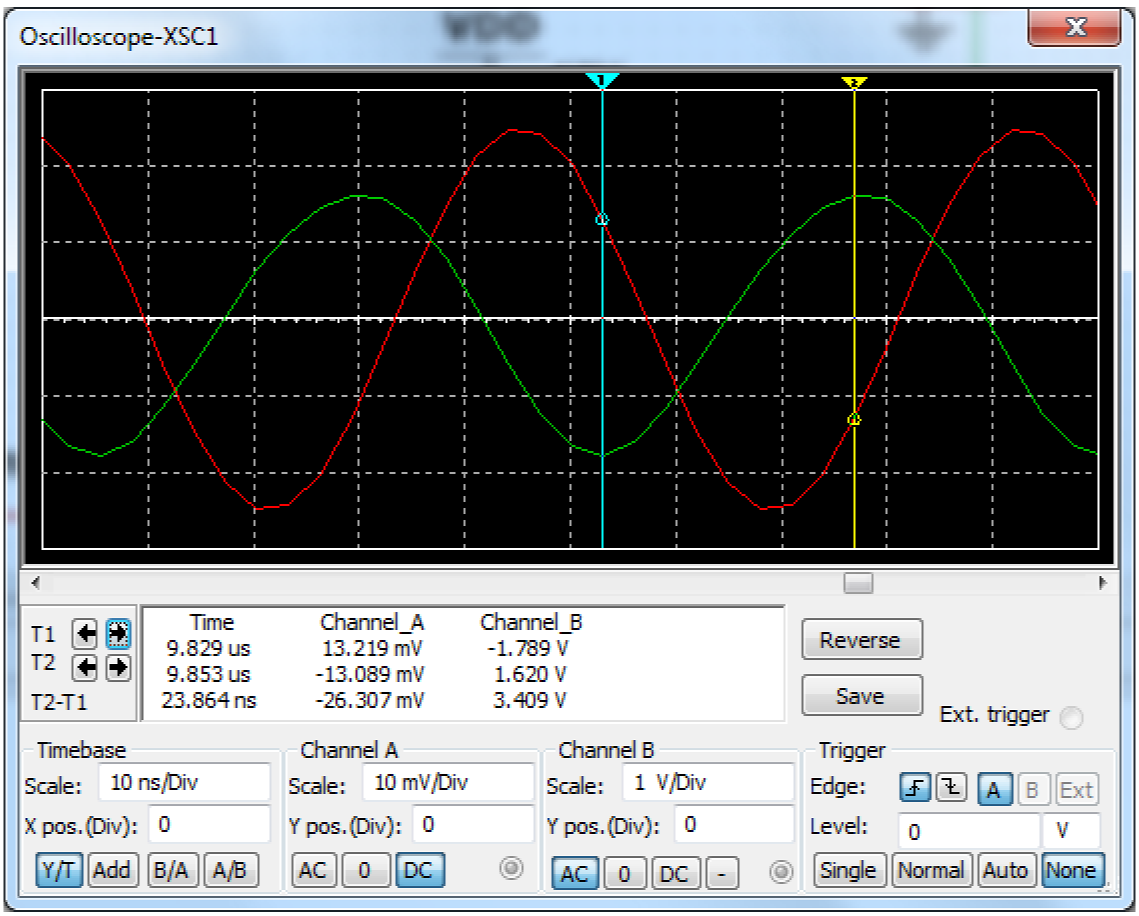


5.1.3 Bandwidth

5. Reset Vin = 50 mVpp at 1.0 KHz.

6. Increase frequency until Av has dropped by 3 db. For Vin held constant at 50 mVpp, this should be where Vout =.7071 * 4.986 Vpp = 3.422 Vpp. For me, this was about 21 MHz, where simulated Vout = 3.409 Vpp.



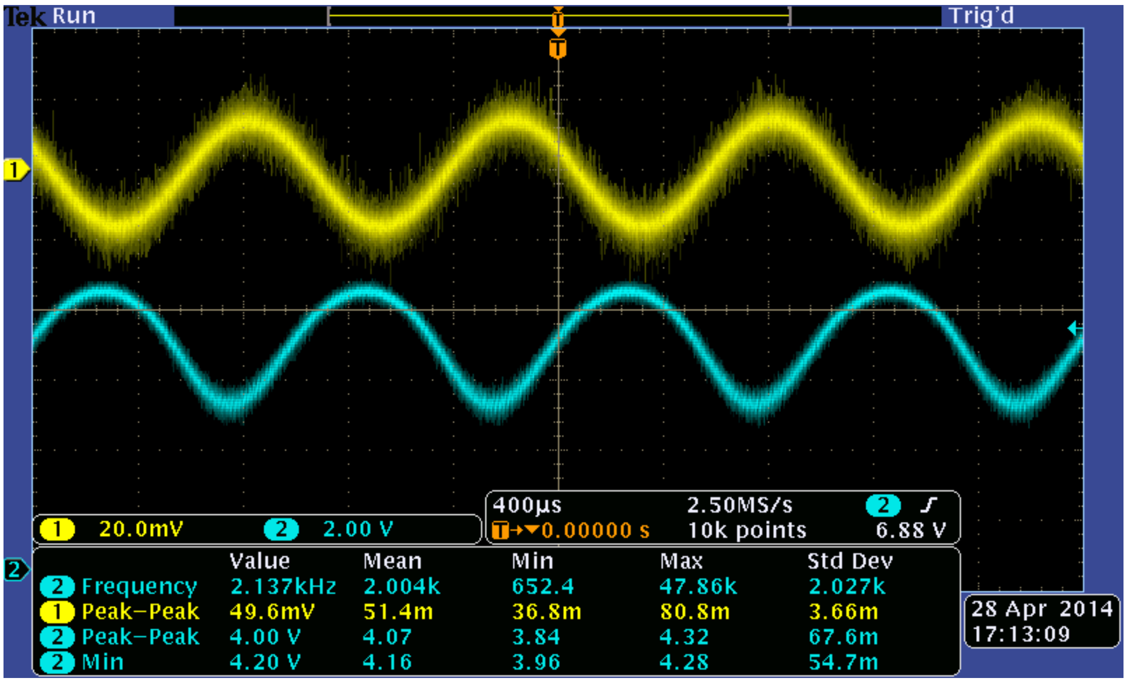


5.2 Measurements

5.3.1 Gain

1. Starting at Vin = 50 mVpp sine wave at 1 KHz, you were asked to adjust Vin so that Vout was as large as possible without clipping. Even at 50 mVpp, the output distorts but our signal generators don't go any lower without building a voltage divider. I will accept results either way.

   Shown here is with Vin = 50 mVpp.

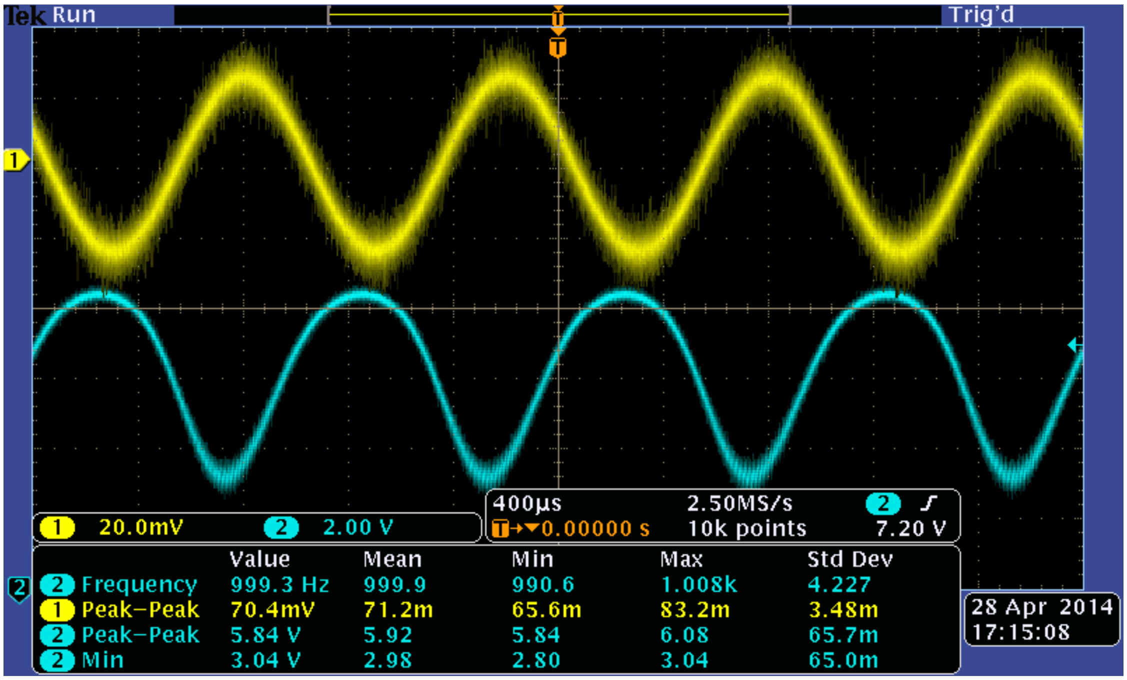


2. This is an inverting amplifier with Av = -4.07 V / 51.4 mV =-79. This is far higher gain than the measured value of Av = 4.72 without C2. But note there is already some visible distortion.

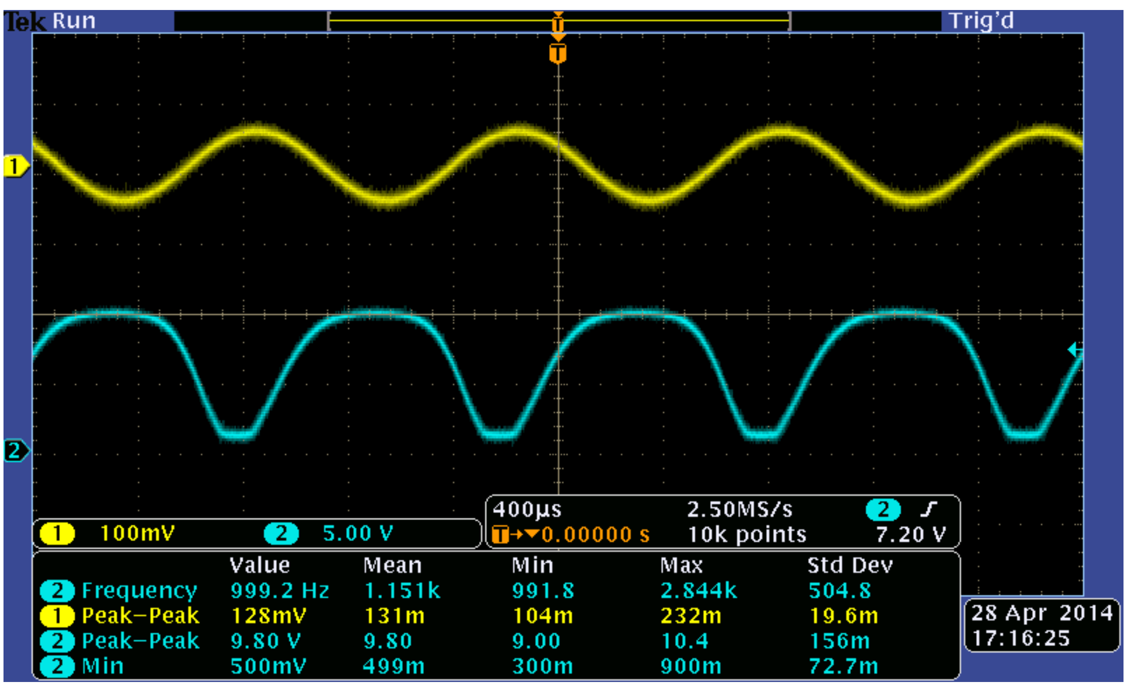
5.3.2 Clipping

3. Increase amplitude until clipping begins. The clipping is rounded at the positive peaks because the transistor's IC curve has a rounded knee as it turns off.

   Clipping is more pronounced here at Vin = 71.2 mVpp, Vout = 5.92 Vpp.

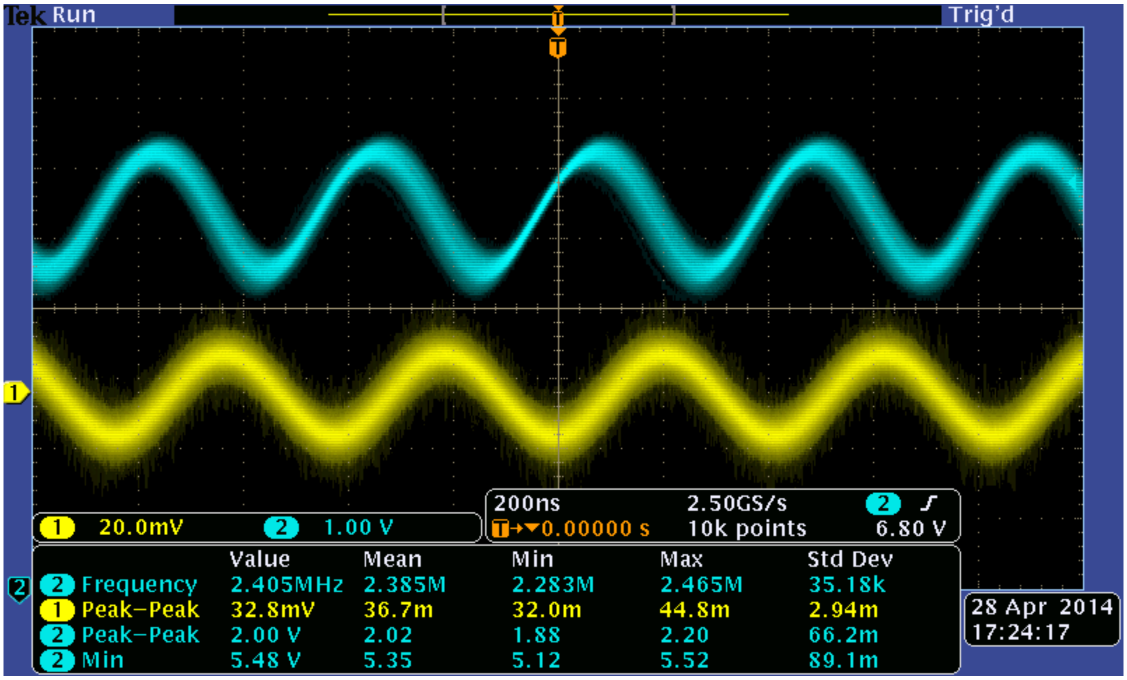


4. Increase until clipping on the opposite peak. Vin = 131 mVpp, Vout = 9.00 Vpp.



5.3.3 Bandwidth

5. Reduce amplitude until pure sine wave, then increase frequency to find the 3db point. Here, Av = 2.02 V / 36.7 mV = 55, down about 30% at 2.4 MHz.



5.4 Questions

1. Is this amplifier inverting or non-inverting.

   Inverting.

2. How do the clipping points compare to those of this amp without C2? Does the presence of C2 affect the clipping levels?

   Negative clipping levels are reduced and it takes a lot smaller input to hit them because the gain is so much higher.

Circuit	Vin clipping	Vin clip both	Vout +clip	Vout –clip
No bypass	1.92 Vpp	2.28 Vpp	10 V	1.68 V
With bypass	70.4 mVpp	128 mVpp	9.85 V	499 mV

3. Calculate the frequency at which the impedance of C2 = RE.

$$XC2 = \frac{1}{2\,\pi\,f\,C} = 1\ K\Omega$$

$$f = \frac{1}{2\,\pi\,C(1\ K)} = 15.9\ Hz$$

4. What is the bandwidth of this amplifier?

About 2.4 MHz for me.

5. How does the bandwidth compare with the unbypassed case?

Not much different for me. But many of you may see a difference.

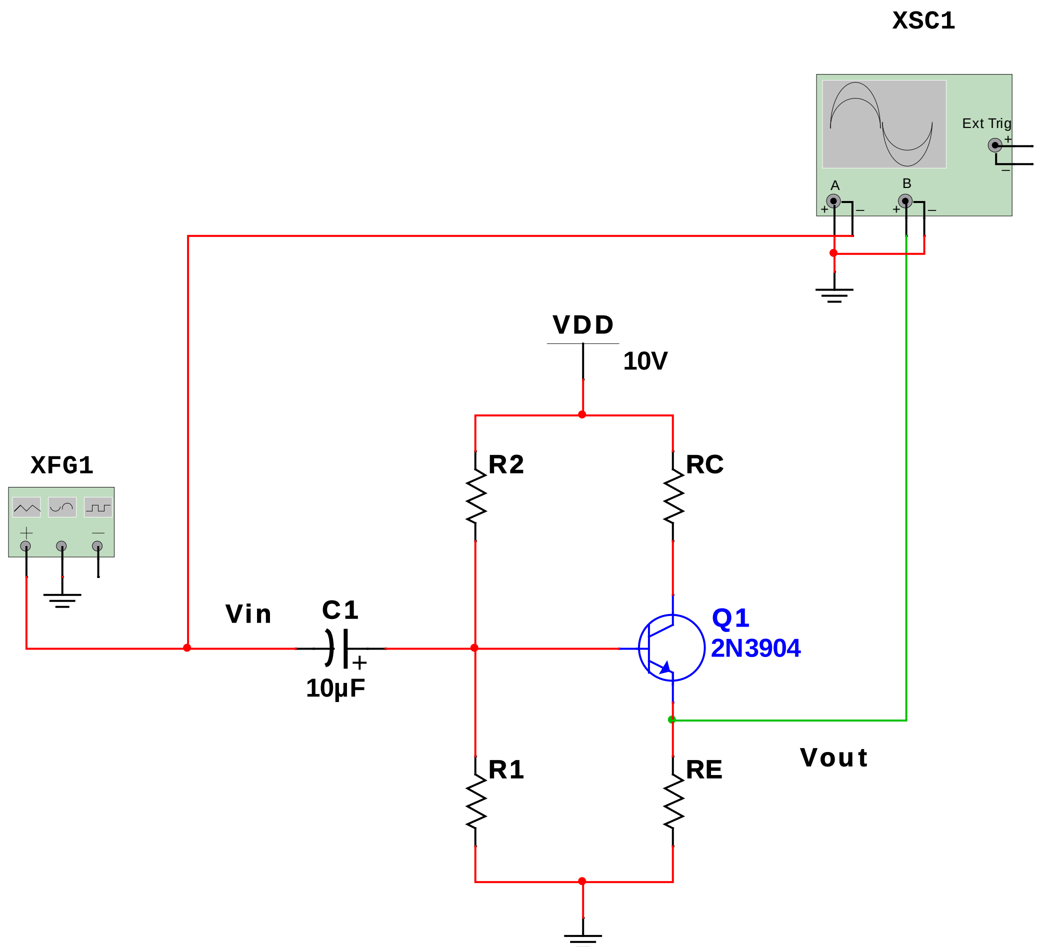
6. Do your measured results agree with your simulation?

Yes, for everything except bandwidth, which measured much lower than predicted by simulation.

Parameter	Simulated	Measured
Av	-99.7	-79
Vin onset of clipping	10 mVpp	71.2 mVpp
Vin clipping both peaks	92 mVpp	131 mVpp
3 dB point	21 MHz	2.4 MHz

6 Common collector amplifier (emitter follower)

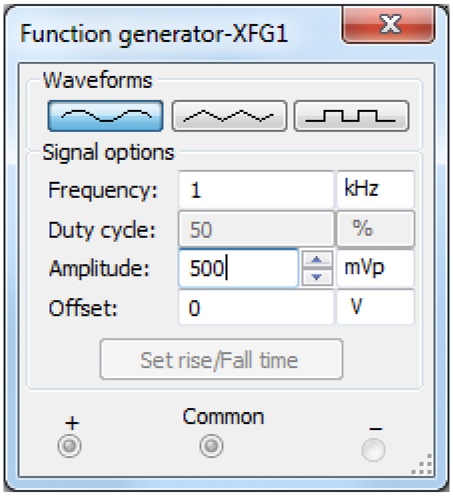
You were asked to simulate and take measurements of this circuit.

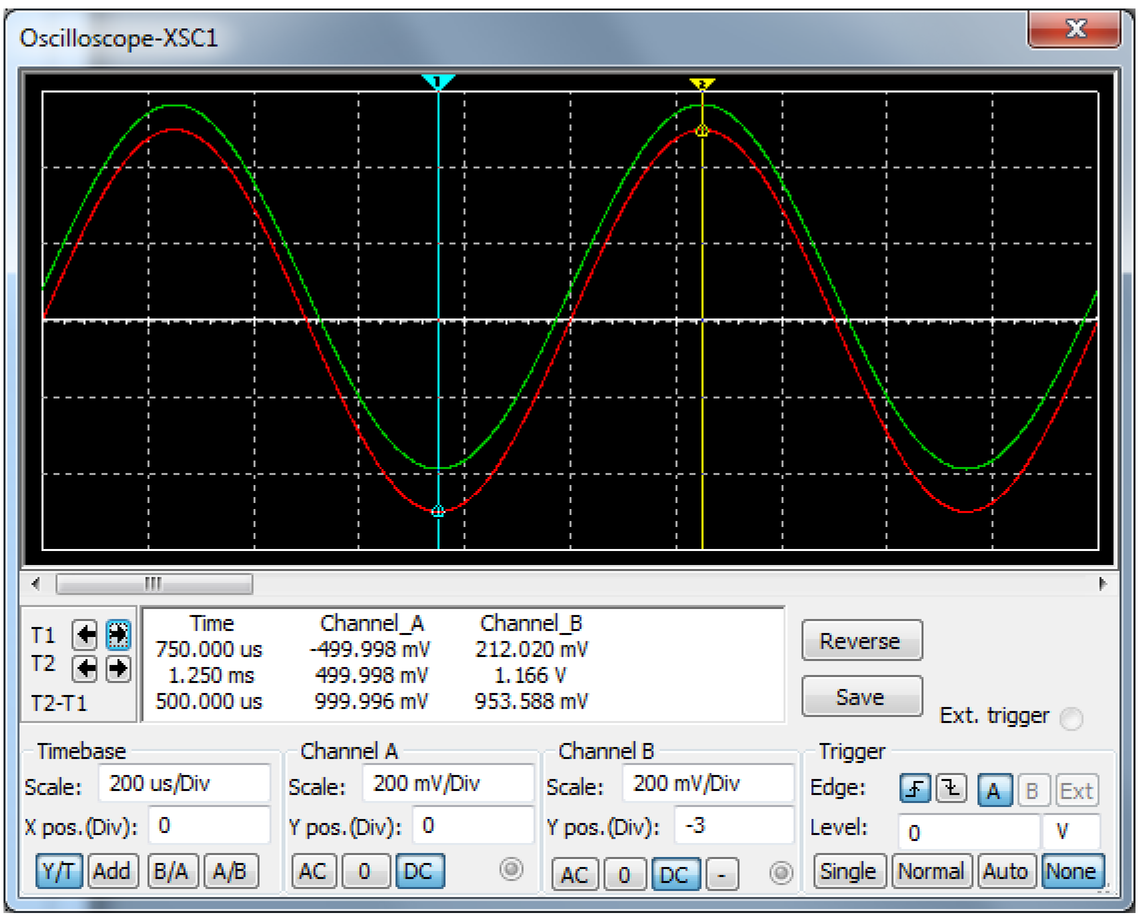


6.1 Simulation

6.1.1 Gain

1. Screenshot of Vin and Vout with Vin = 1.0 Vpp sine wave at 1.0 KHz.

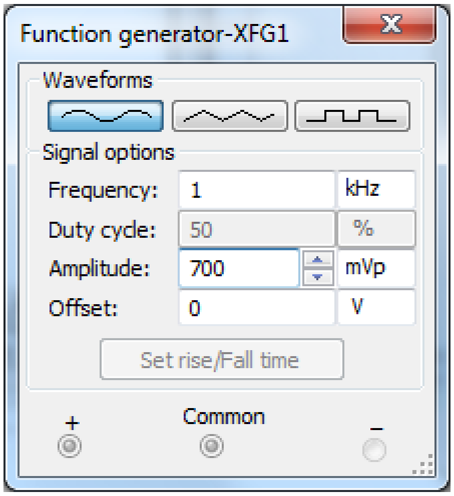


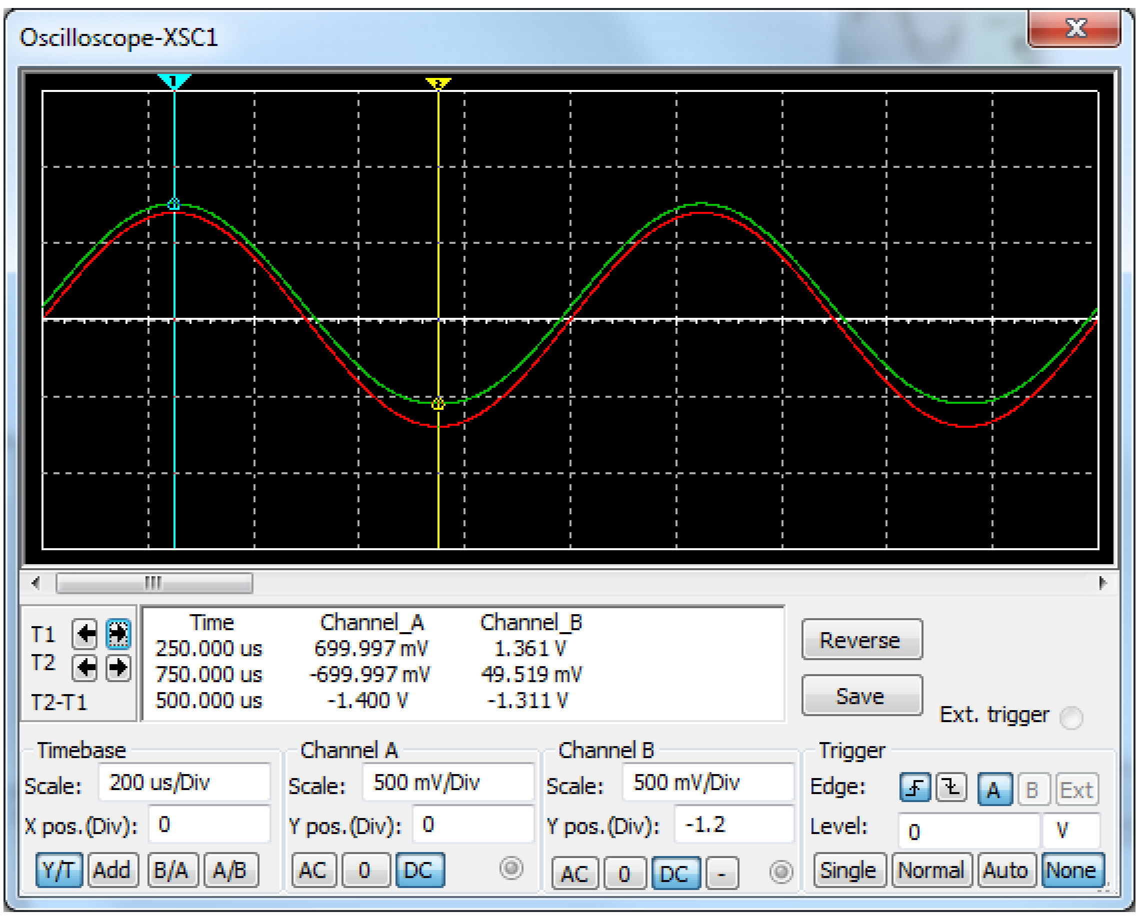


2. Av = 953.588 mVpp / 1.0 Vpp = 0.95.

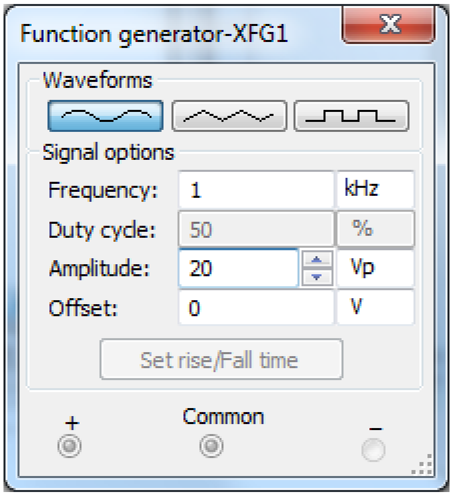
6.1.2 Clipping

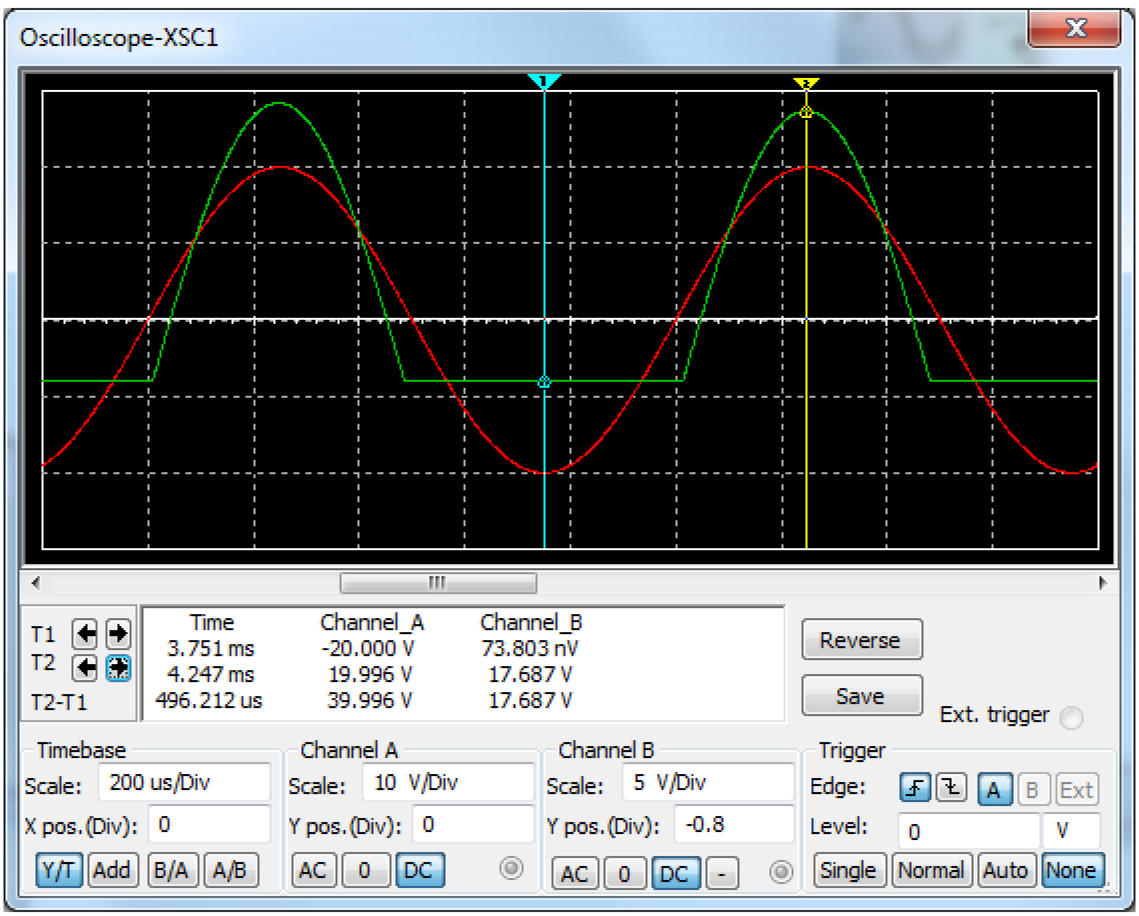
3. Onset of clipping shown here at Vin = 700 mVp = 1.4 Vpp, Vout = 1.311 Vpp.





4. Continue increasing Vin until it clips on both peaks. This never happens. Shown here is with Vin = 20 Vp = 40 Vpp. The reason it never clips positive is because the transistor always maintains a constant VBE and VE < VB.

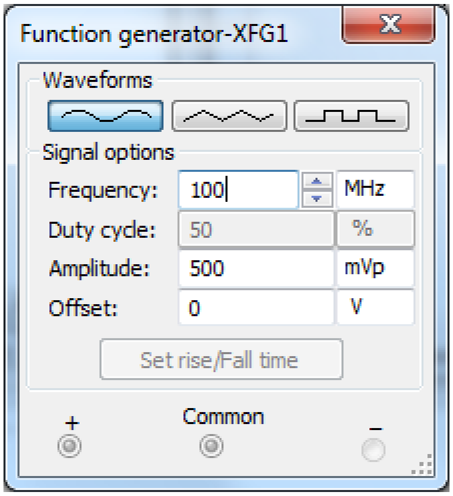


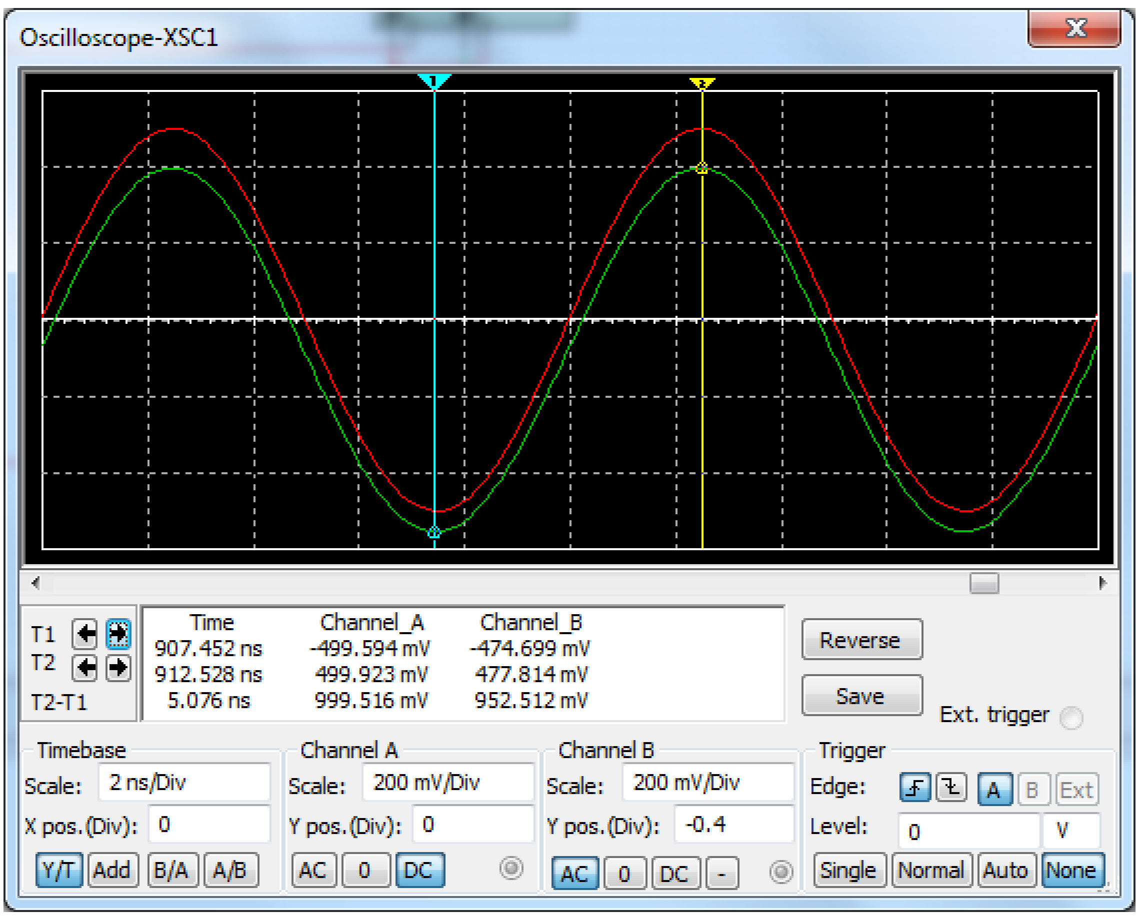


6.1.3 Bandwidth

5. Reset Vin = 1.0 Vpp at 1.0 KHz.

6. Increase frequency to find the 3 dB point. For constant amplitude Vin, this is where Vout = .7071 * 953.588 mVpp = 674.2 mVpp. In simulation, gain is flat to at least 100 MHz, shown here.

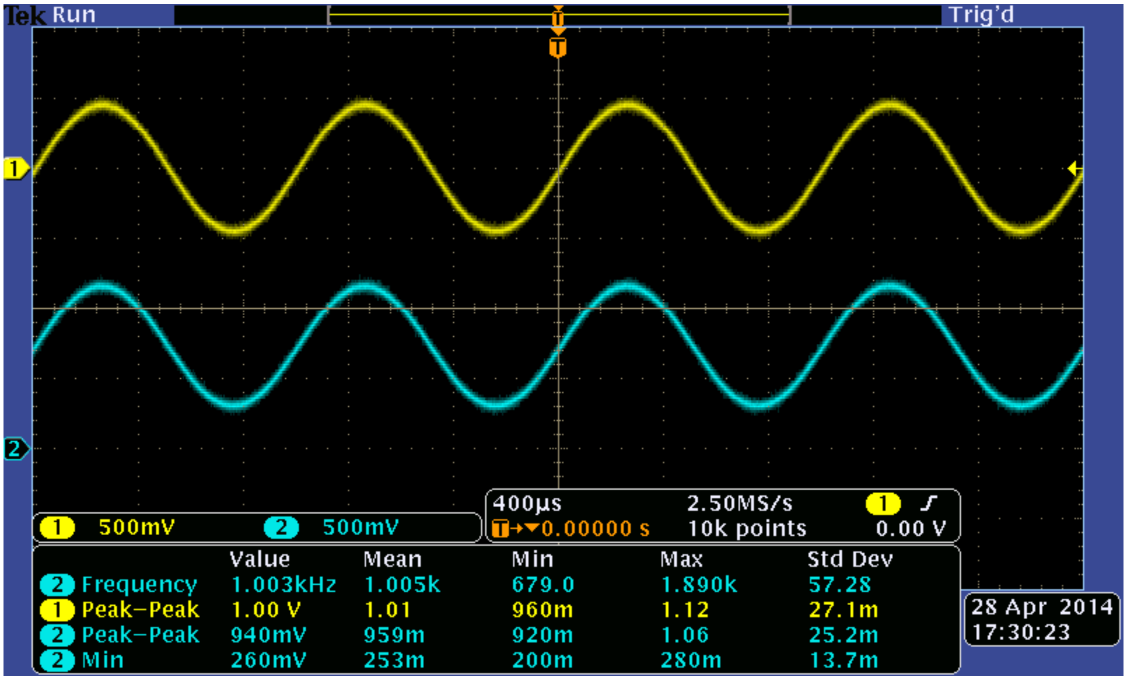




6.3 Measurements

6.3.1 Gain

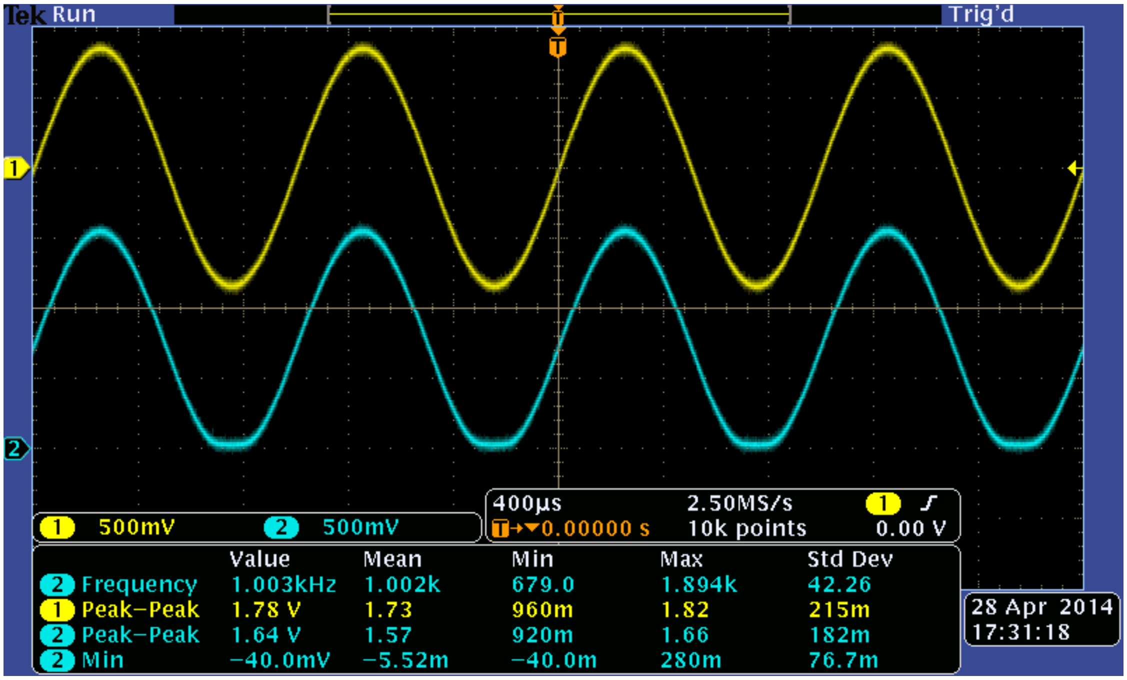
1. Initially Vin =1 Vpp sine wave @ 1 KHz.



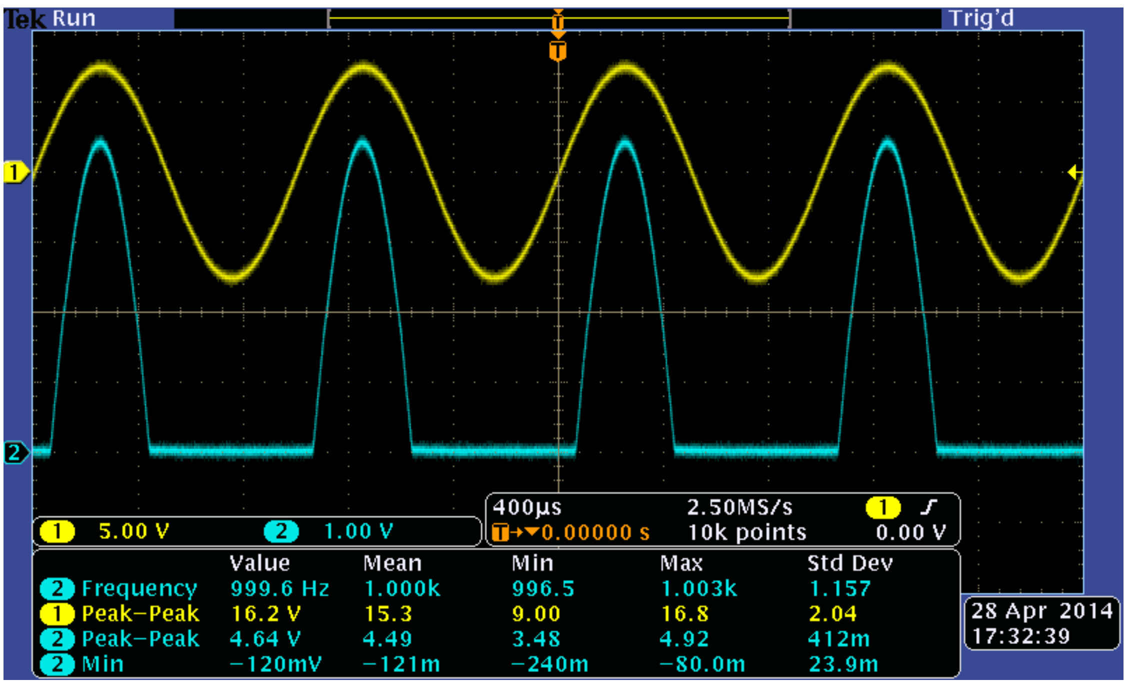
2. Av = 959 mV / 1.01 V = 0.95.

6.3.2 Clipping

3. Increase Vin until clipping. Note that it clips at the bottom as the transistors switches off. Clipping is rounded because there's a rounded knee in the IC curve.



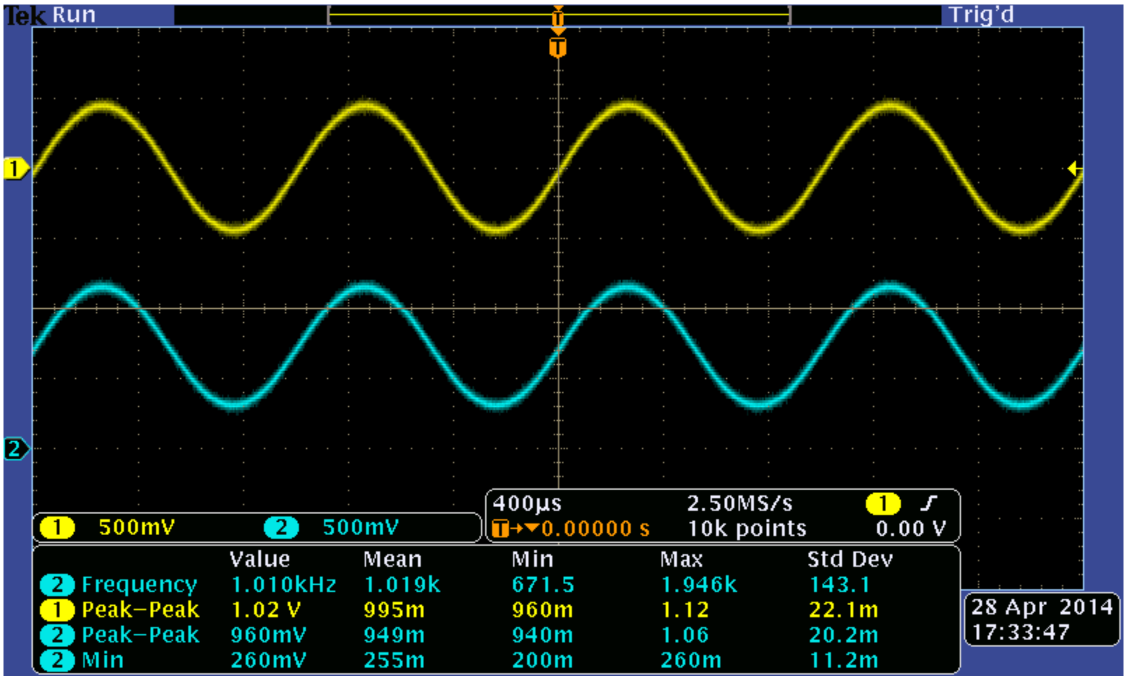
4. Never clips on the other side.



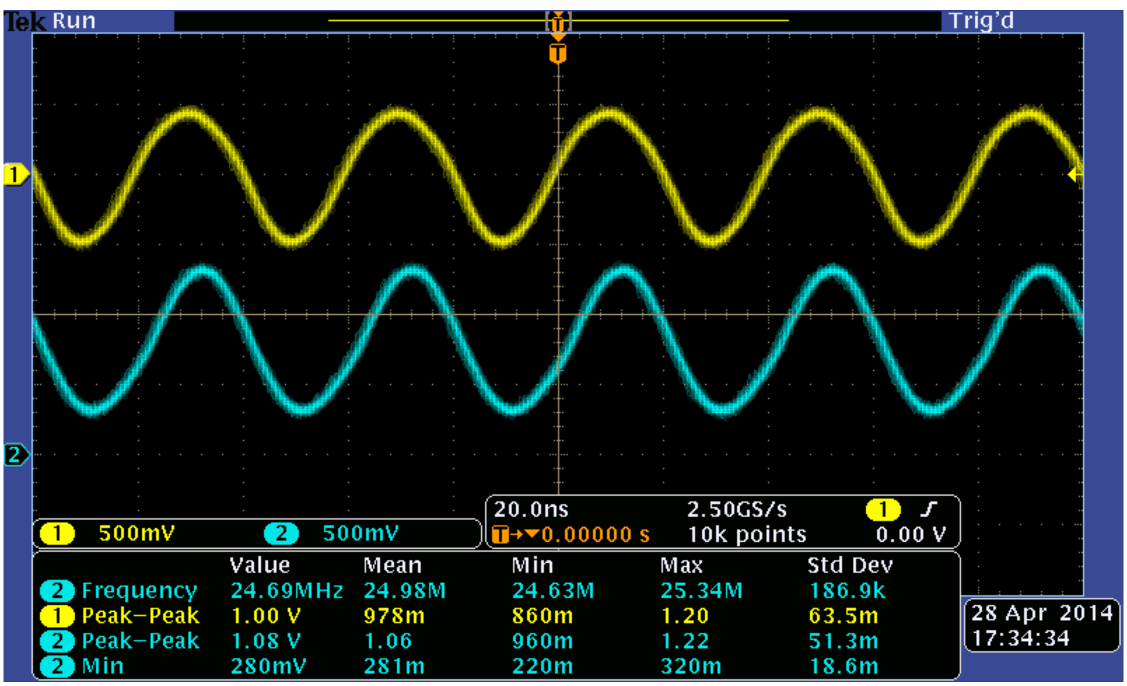
(Some of you have screenshots that show blips at the bottom. The function generator I used had a maximum output of 16 Vpp. But if you use a function generator that can generator a greater amplitude output, you can drive the transistor into reverse breakdown.)

6.3.3 Bandwidth

5. Reduce amplitude to no clipping.



6. Find 3db frequency. At 25 MHz limit of the function generator, still no falloff.



1. Is this amp inverting or non-inverting?

   Non-inverting.

2. Since Av < 1, what is the usefulness of this amplifier?

   Greater current drive, e.g., to drive a low-impedance load like a loudspeaker, and very flat response.

   Remember: $IE = (\beta + 1) * IB$

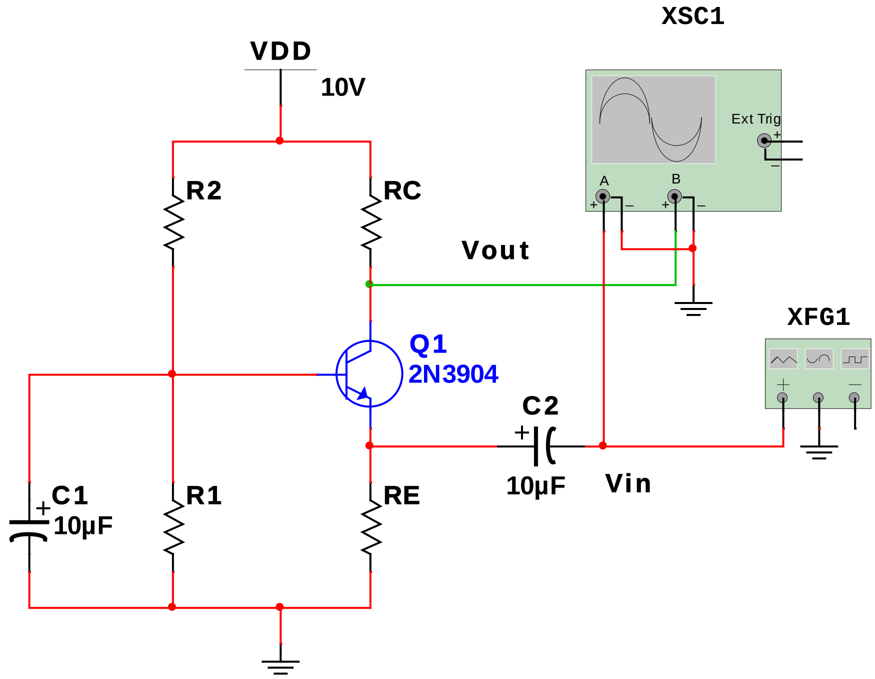
3. Do your measured results agree with your simulation?

   Yes, reasonably closely.

Parameter	Simulated	Measured
Av	0.95	0.95
Vin onset of clipping	700 mVpp	1.78 Vpp
Vin clipping both peaks	> 40 Vpp	> 16 Vpp
3 dB point	> 100 MHz	> 25 MHz

7 Common base amplifier

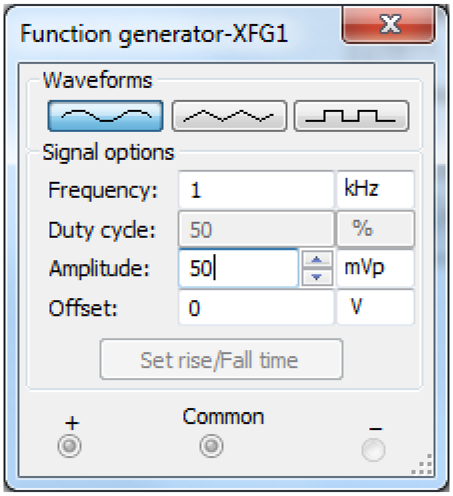
You were asked to simulate and take measurements of this circuit.

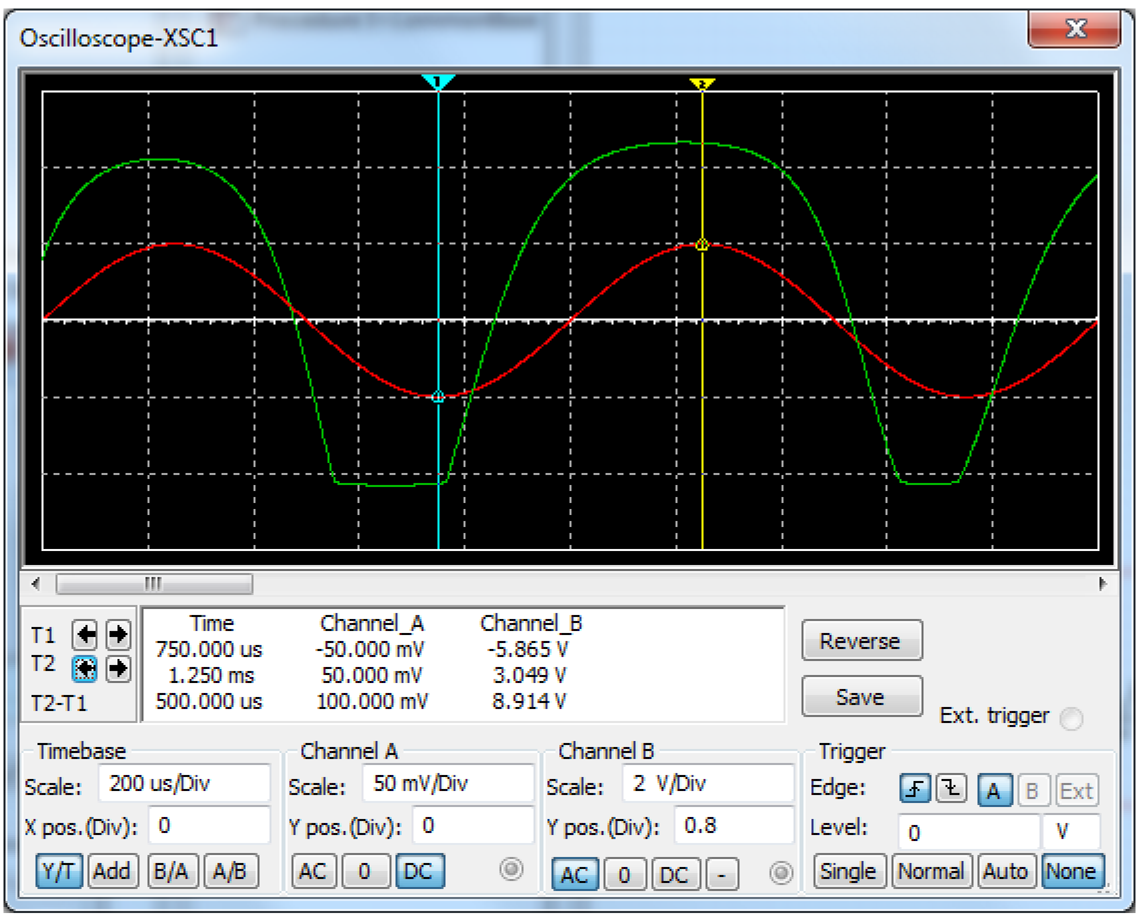


7.1 Simulation

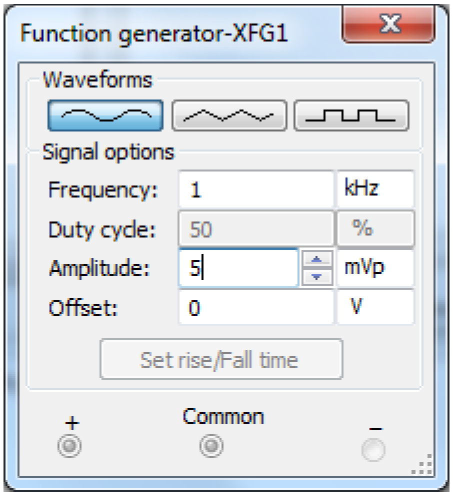
7.1.1 Gain

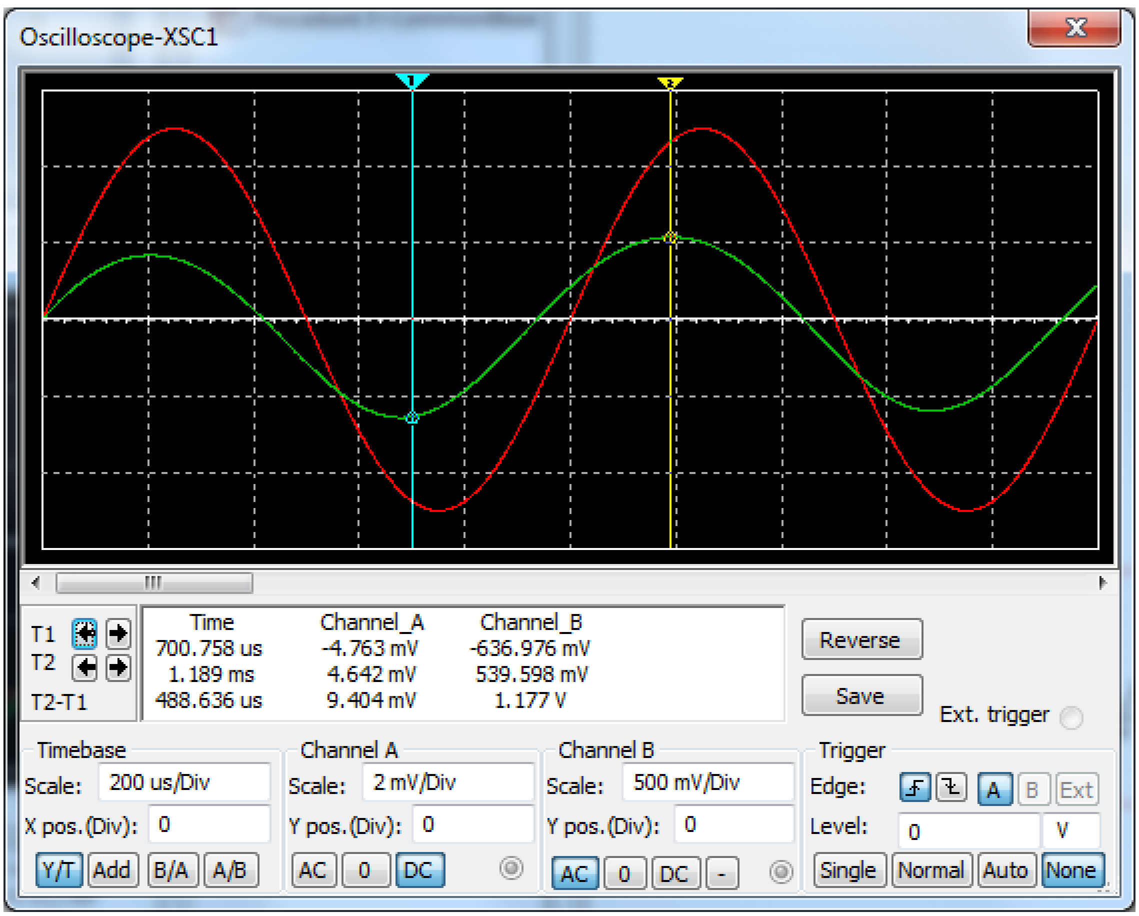
1. Screenshot of Vin and Vout with Vin = 100 mVpp at 1.0 KHz. Notice there it's already clipping top and bottom.





To avoid distortion, I had to reduce the input to Vin = 10 mVpp.

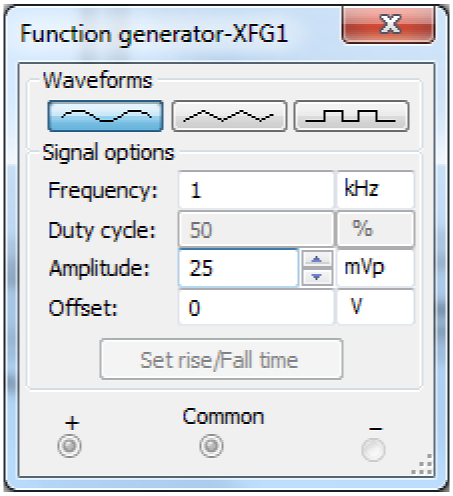


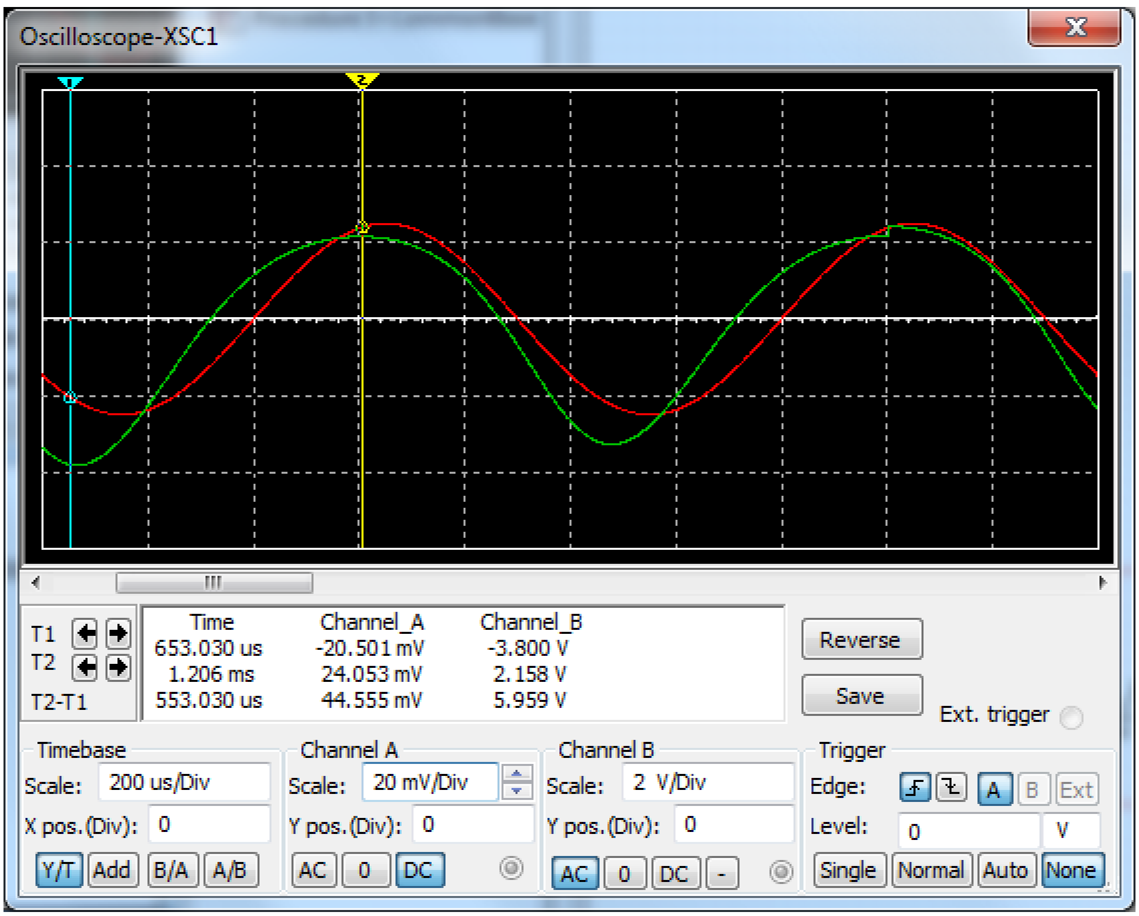


2. Av =1.177 Vpp / 10 mVpp = 117.7.

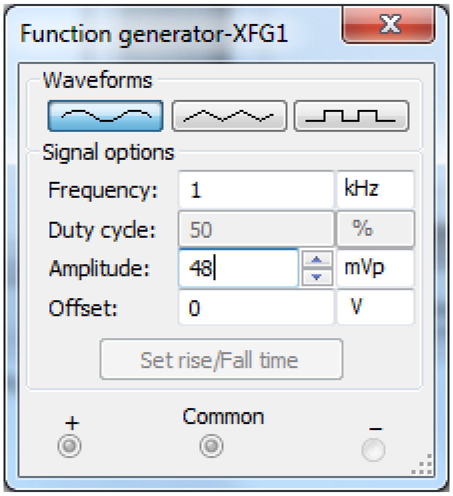
7.1.2 Clipping

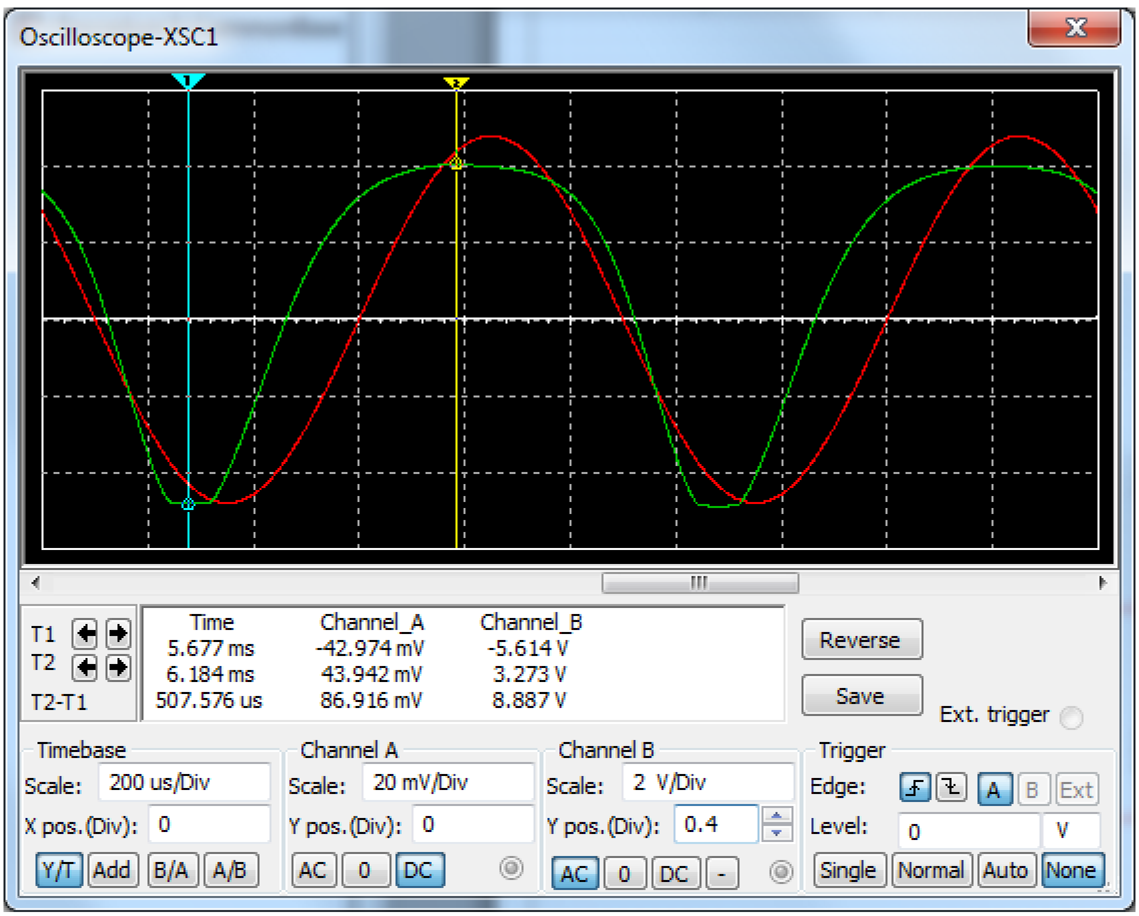
3. Clipping on one peak at Vin = 25 mVp = 50 mVpp, Vout = 5.959 Vpp.





4. Clipping on both peaks at Vin = 48 mVp = 96 mVpp, Vout = 8.887 Vpp.

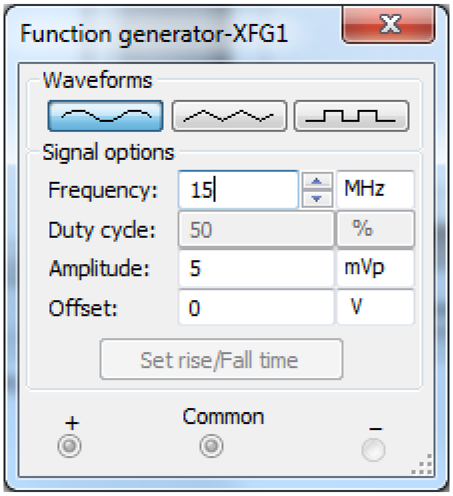


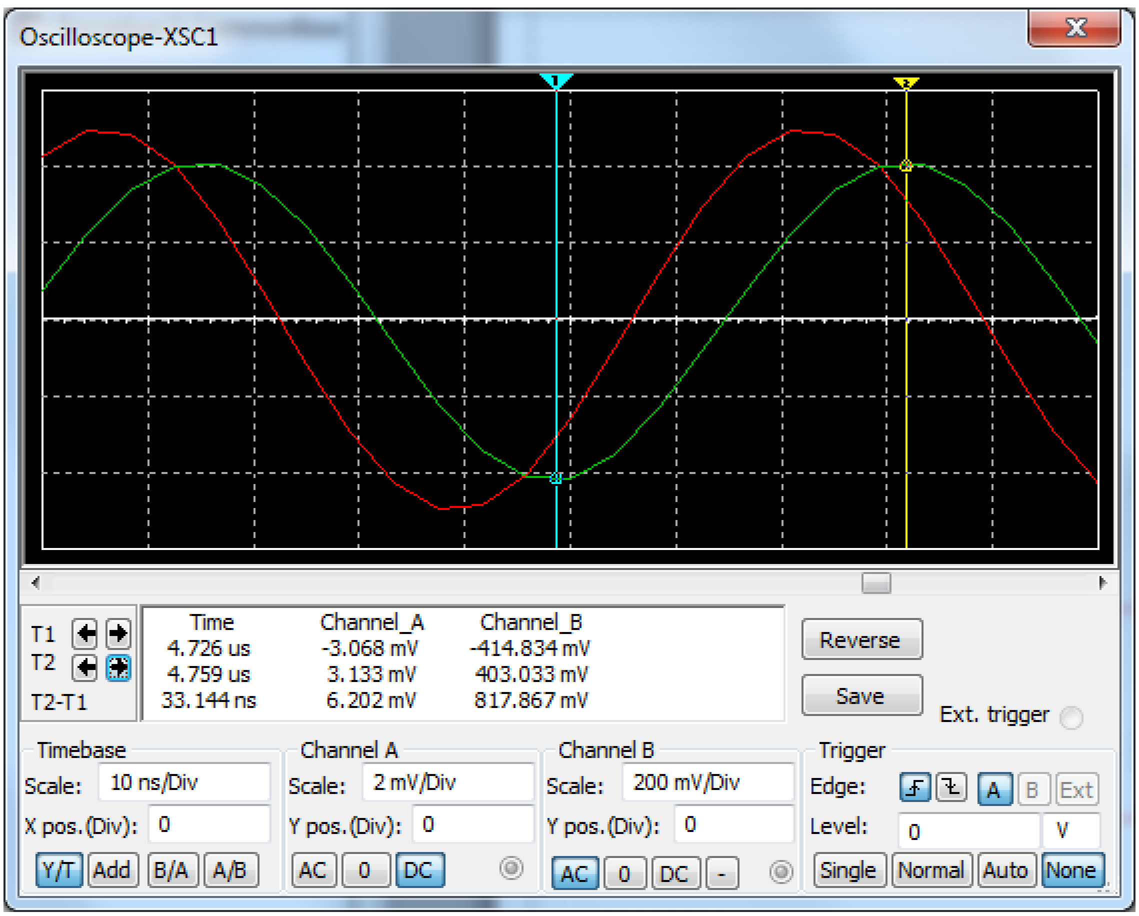


7.1.3 Bandwidth

5. Reduce Vin until Vout not clipped. As before, Vin = 5 Vp = 10 Vpp, Vout = 1.177 Vpp.

6. The 3 dB point for constant amplitude Vin is where Vout = .7071 * 1.177 Vpp = 0.832 Vpp. Shown here is Vout = 817.9 mVpp at 15 MHz.

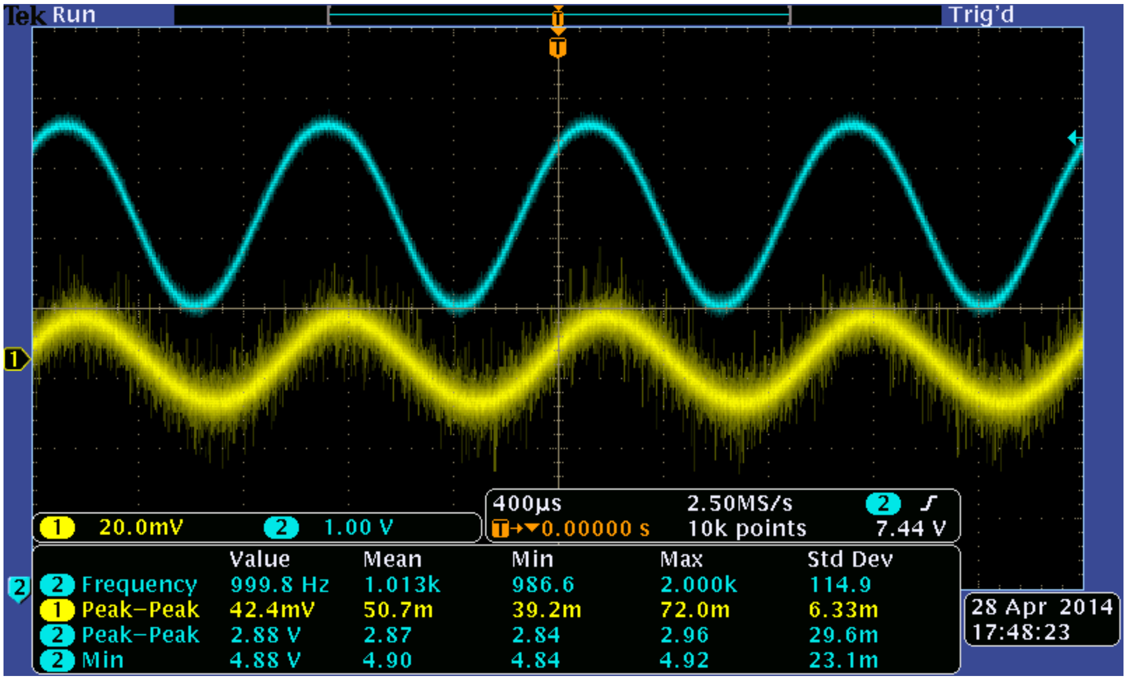




7.3 Measurement

7.3.1 Gain

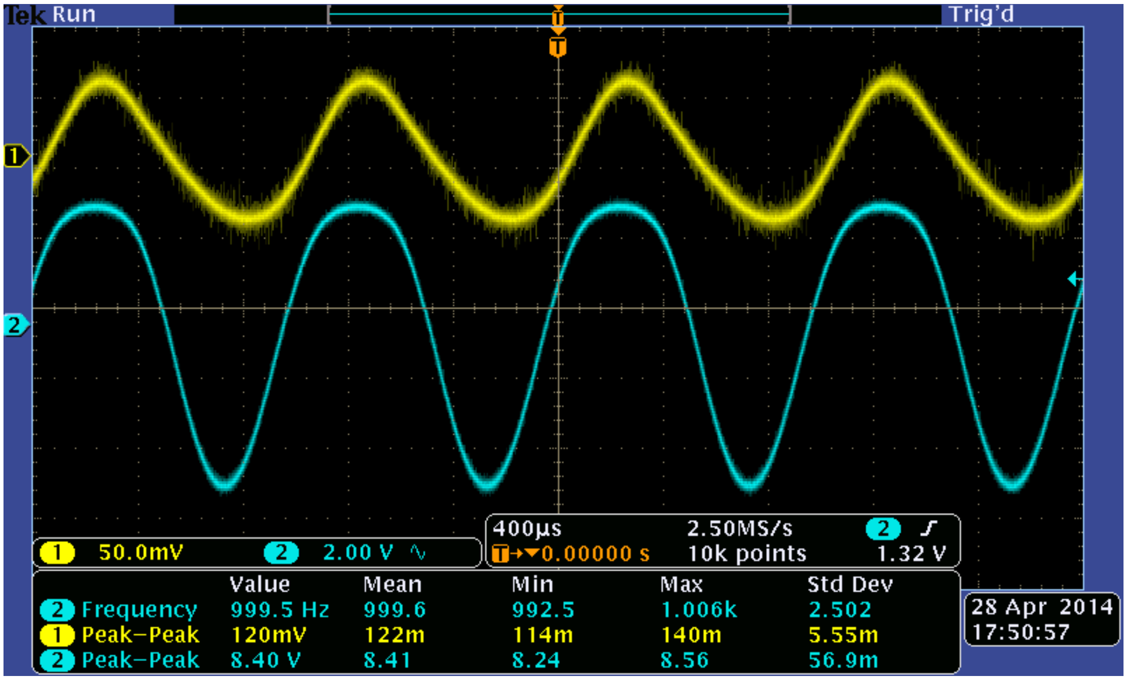
1. Set Vin as large as possible without clipping.



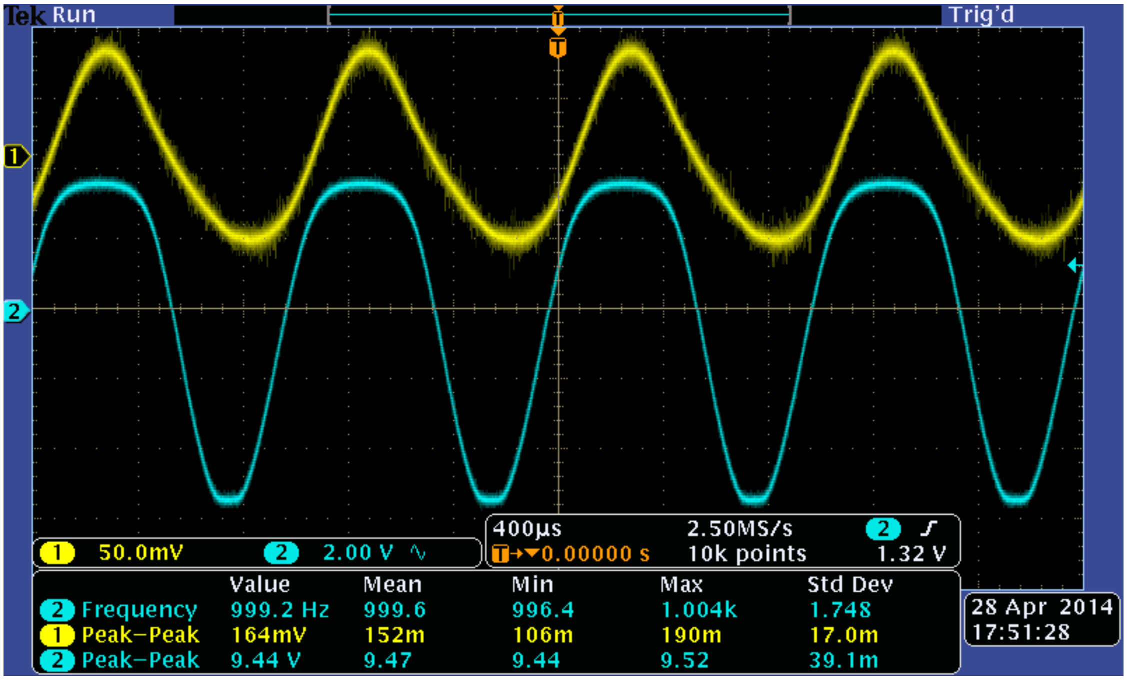
2. Shown here, Av = 2.87 V / 50.7 mV = 57.

7.3.2 Clipping

3. Increase Vin until clipping. Note how the low impedance input is loading the function generator. Shown here, Vin = 122 mVpp, Vout = 8.41 Vpp.

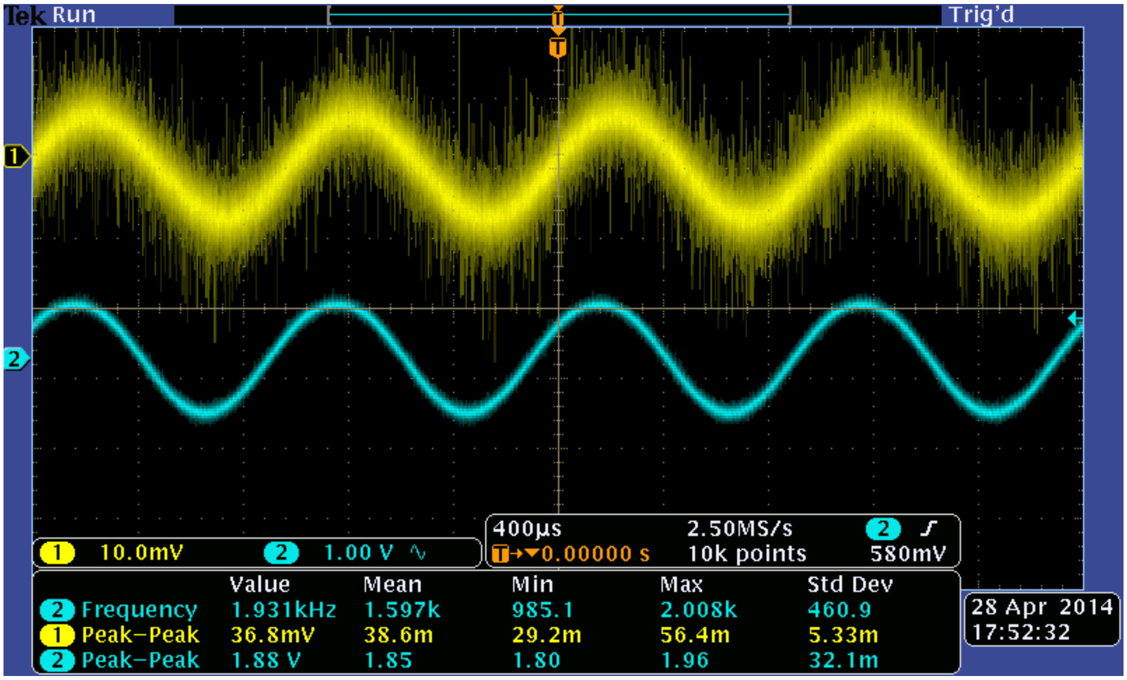


4. Increase Vin until clips both sides. Shown here, Vin = 152 mVpp, Vout = 9.47 Vpp.

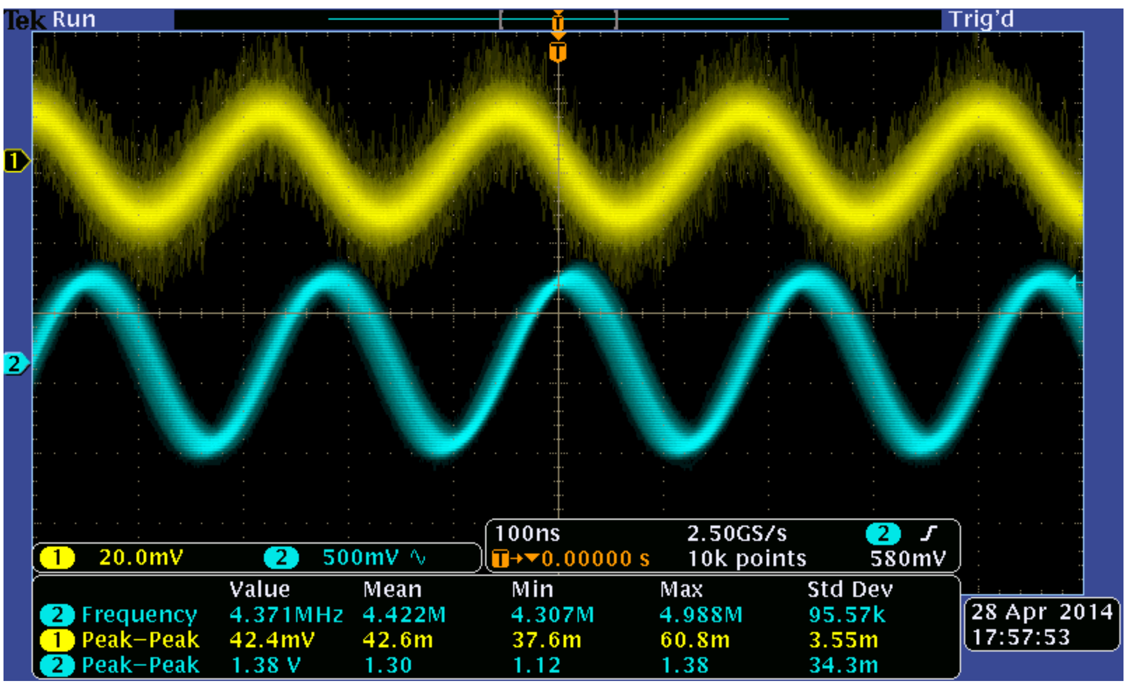


7.3.3 Bandwidth

5. Reduce Vin until no clipping. Shown here, Av = 1.85 V / 38.6 mV = 48.



6. Find 3db frequency. Shown here, Av = 1.30 V / 42.6 mV = 30, down about 36% at 4.4 MHz.



7.4 Questions

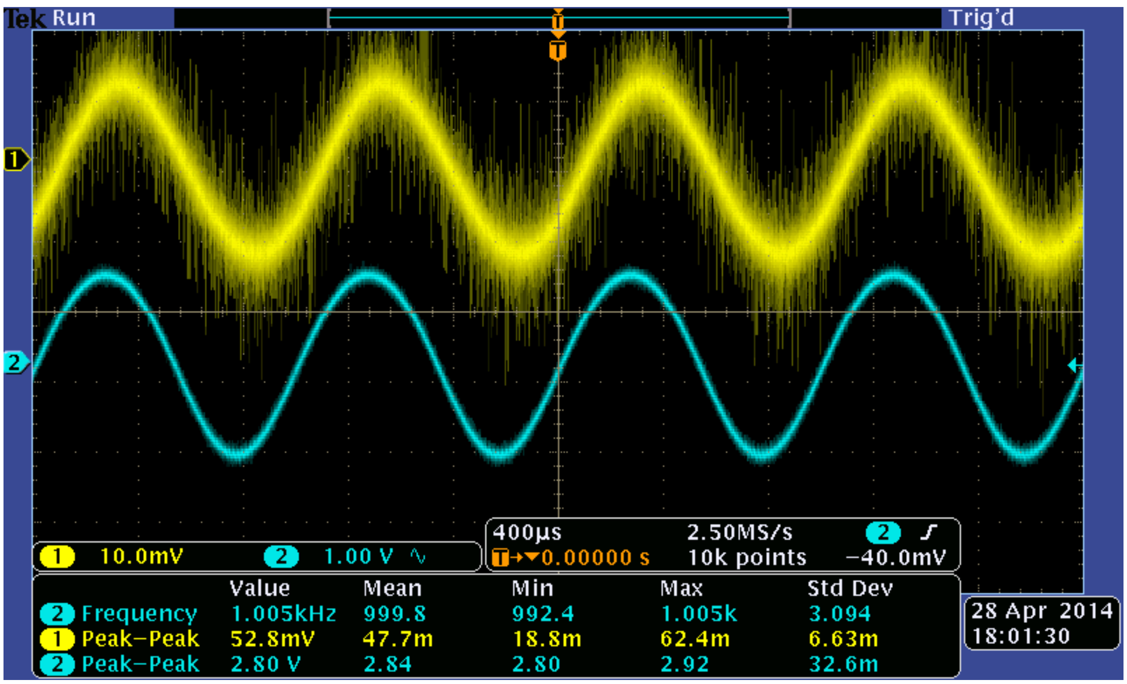
1. Is this amplifier inverting or non-inverting?

   Non-inverting.

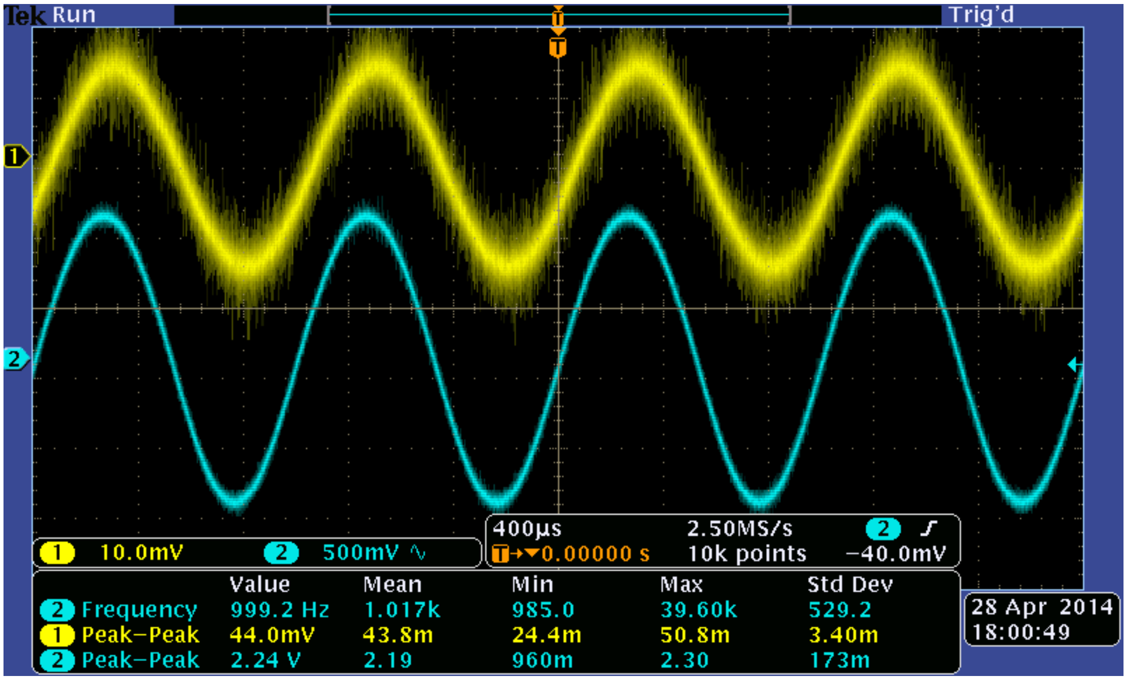
2. Speculate on what happens if the C1 bypass resistor is removed.

   The AC small signal path will be through R1, reducing vb.

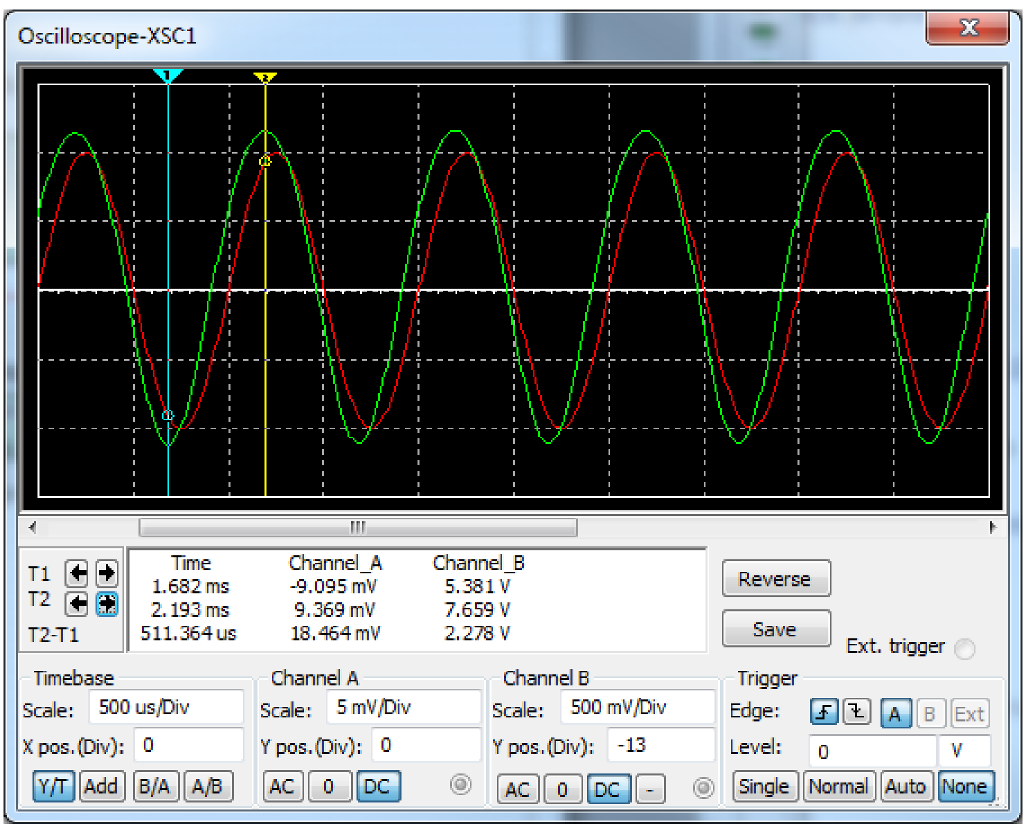
   Here's a screenshot with the bypass, showing Av = 2.84 V / 47.7 mV = 59.5.



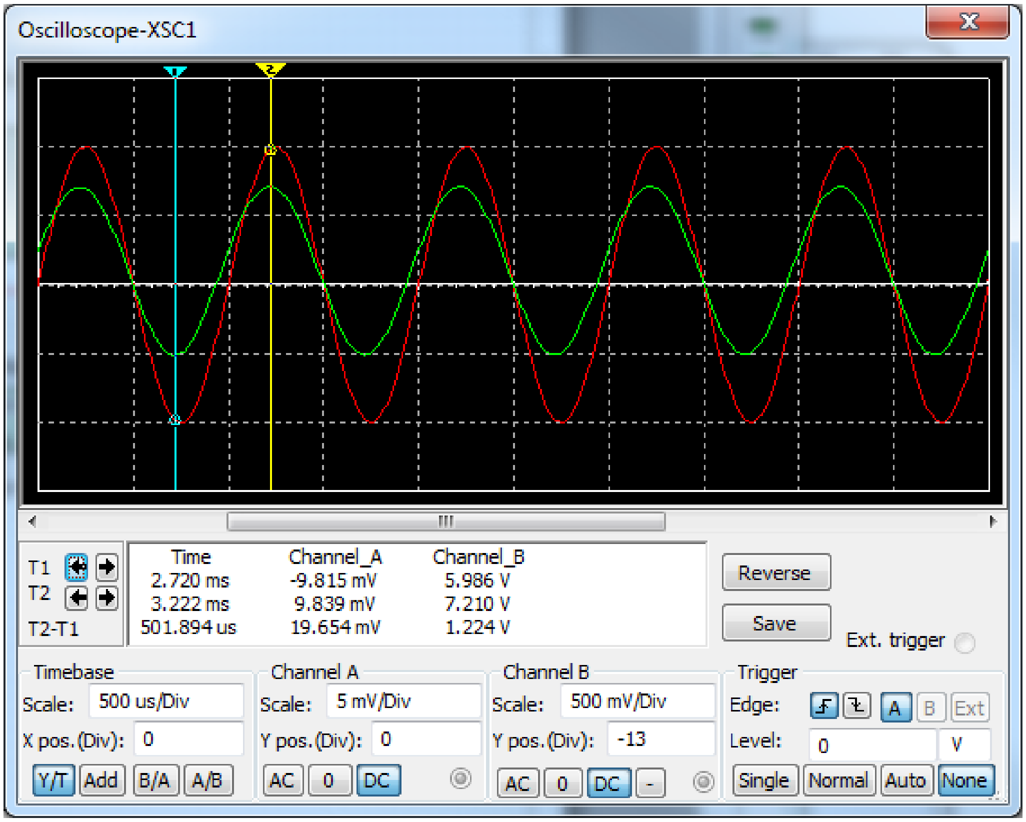
   Here it is without the bypass, showing Av = 2.19 V / 43.8 mV = 50, a decrease of 16%.



Simulation predicts a larger decrease without C1. Shown here with C1 and Vin = 20 mVpp, 1KHz, Av = 2.278 V / 20 mV = 114.



Without C1, Av = 1.224 V / 20 mV = 61, a decrease of 46%.



3. Explain why the base of a BJT is never useful as an amplifier output.

   The output would be $1/\beta$ times the input.

4. Explain why the collector of a BJT is never useful as an amplifier input.

   It would have to be operated in reverse active, but β_R is really small.

5. Do your measured results agree with your simulation?

   Gain was less than predicted by simulation, which affected the clipping levels, e.g., (117.7/57) * 50 mVpp = 103 mVpp. As before, the simulation is optimistic on bandwidth.

Parameter	Simulated	Measured
Av	117.7	57
Vin onset of clipping	50 mVpp	122 mVpp
Vin clipping both peaks	96 mVpp	152 mVpp
3 dB point	15 MHz	4.4 MHz