Exercise:
Simulating a Diode

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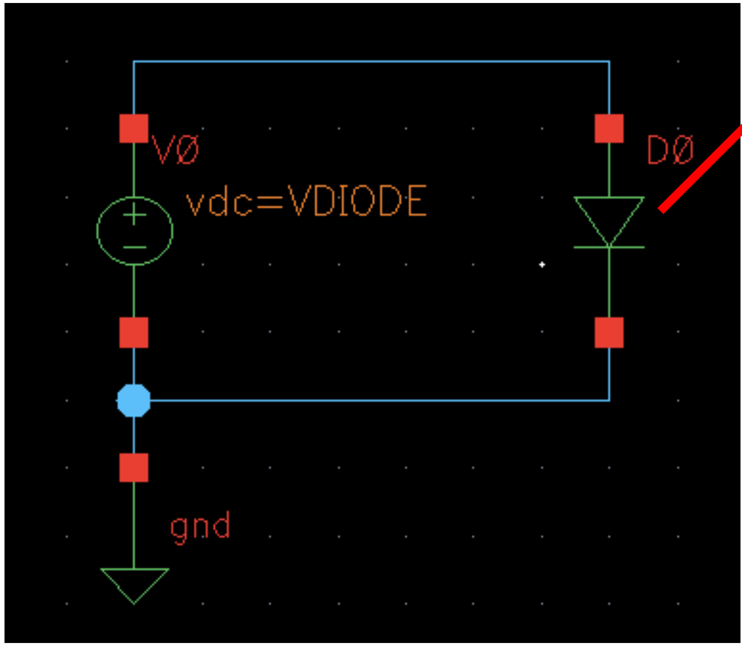
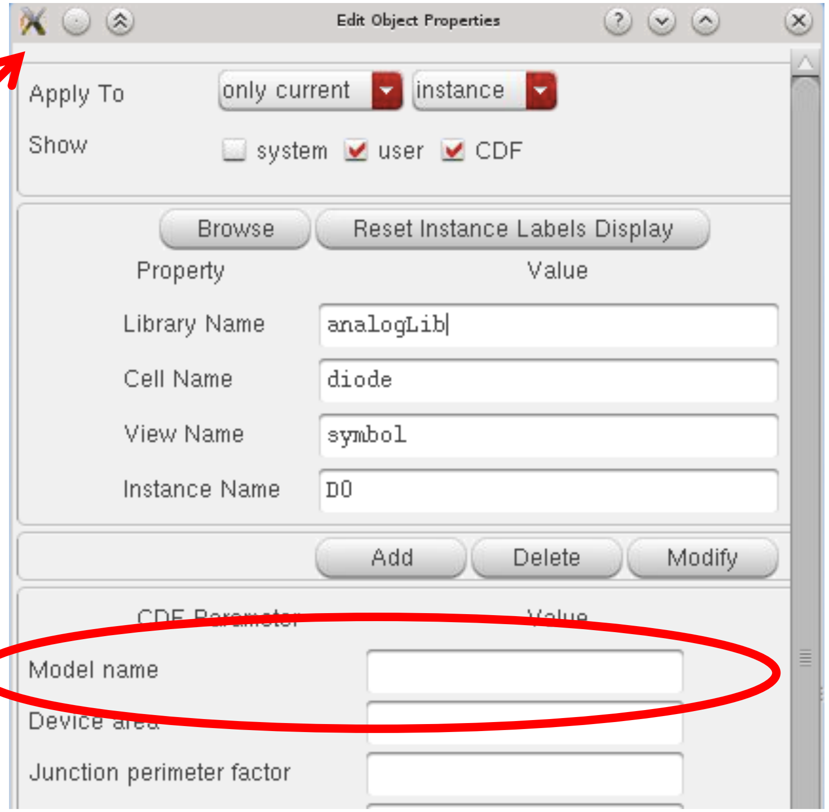
1. Defining a Model

- Create the following schematic.
  - The diode is taken from `analogLib`
  - Note that NO model is associated to this 'generic' diode





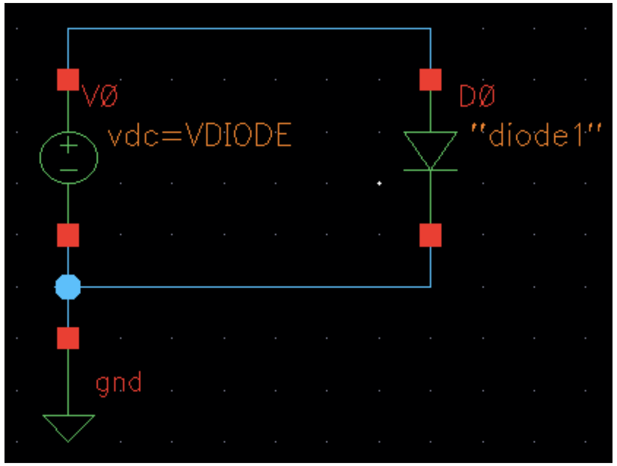
Trying a DC simulation

- Simulate (DC!) the diode current for VDIODE = 0…1V
  - An error occurs:

```
Error found by spectre during hierarchy flattening.
    ERROR (CMI-2119): D0: Instance (of type diode) requires the use of a model.
```

'No model given'

- Now assign a model with name '`diode1`' to the diode:



- Run the simulation again:

```
Error found by spectre during circuit read-in.
    ERROR (SFE-23): "input.scs" 36: The instance `D0' is referencing an undefined model
```

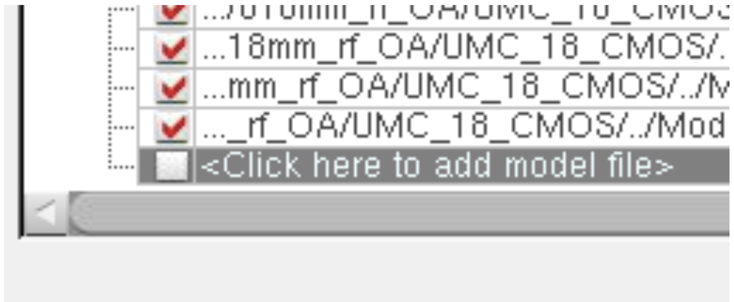
'model given, but not defined / found'

Defining a Model

- Create a text file `MyDiode.lib` with the following model definition:

```
.MODEL diode1 d IS=1e-08 RS=1 CJO=1e-11 VJ=0.7 M=0.5
```

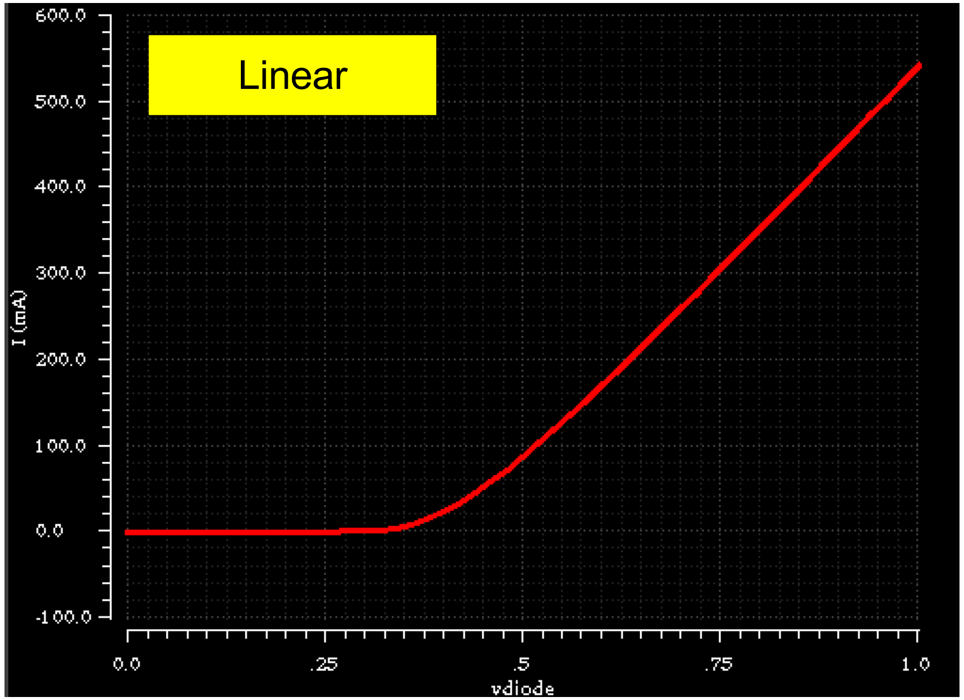
- The simulator needs to know about this file:
  - In `Setup->Model Libraries...`, add your file `MyDiode.lib`.

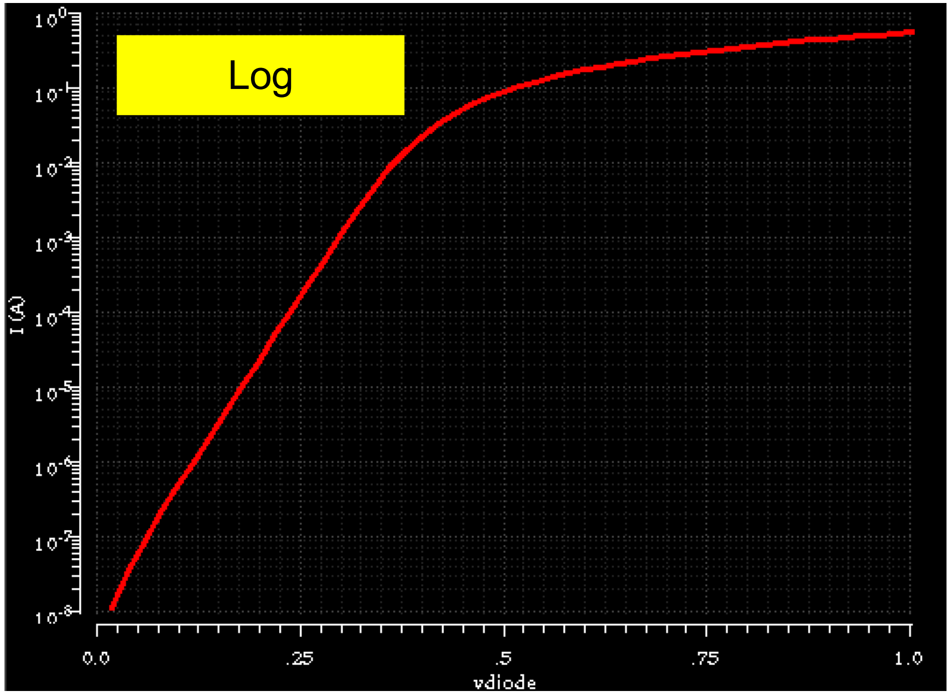


- Run the simulation again.
- Does the current increase exponentially? Try a log current scale! Sweep only to 0.4V! Why does I(U) become linear?

Solution 1

- Sweeping to 1 V with this diode gives currents of several 100mA!

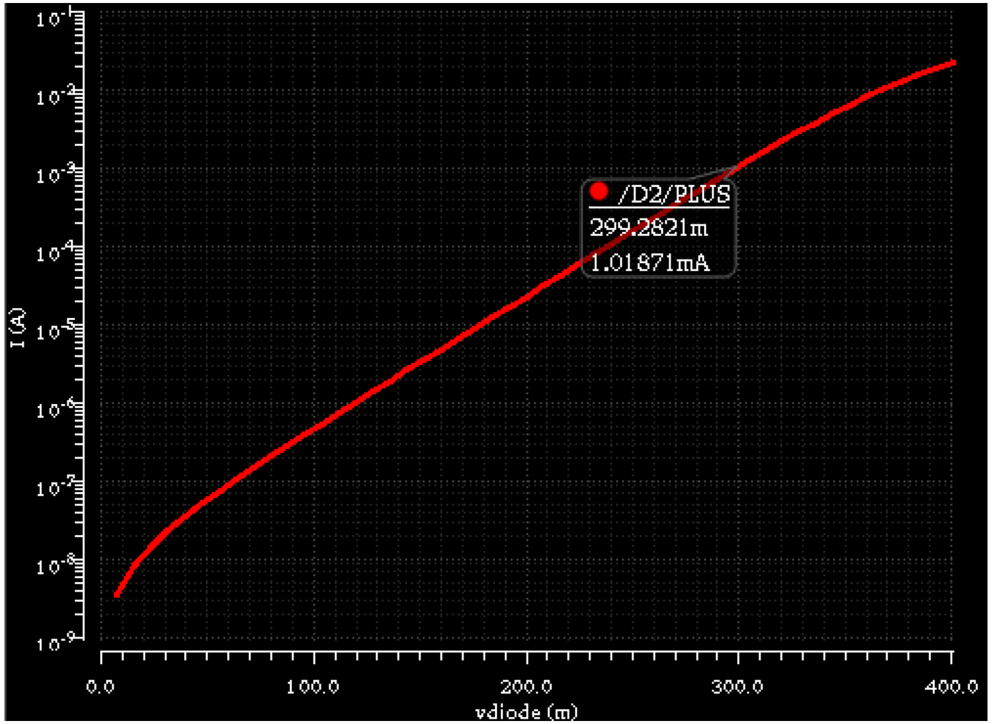




- In Log scale we can see, that the expected exponential behaviour stops at ~ 0.3V at some 10mA
- The reason is the series resistor R=1Ω which generates a voltage drop of 10mV for 10mA..

Solution 1

- For 0..400mV:



- For 300mV, the resistor makes nearly no effect.
- The expected current at 300mV for an ideal diode is $I(0.3V) = IS\ (e^{300/25.86} - 1) = 1.09$ mA, as simulated

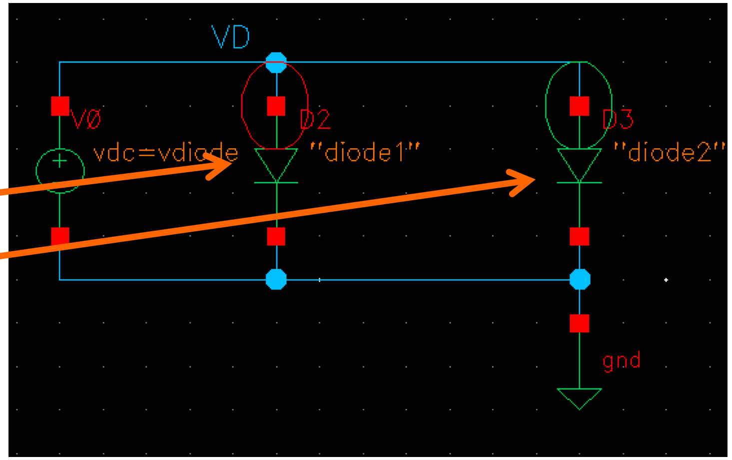
2. Different Models

- Instantiate a second diode with another model ‘`diode2`’
- Add model ‘`diode2`‘ to your `MyDiode.lib`. Change for instance IS to 2e-8.
- Simulate and compare the two diode currents (best in log scale)

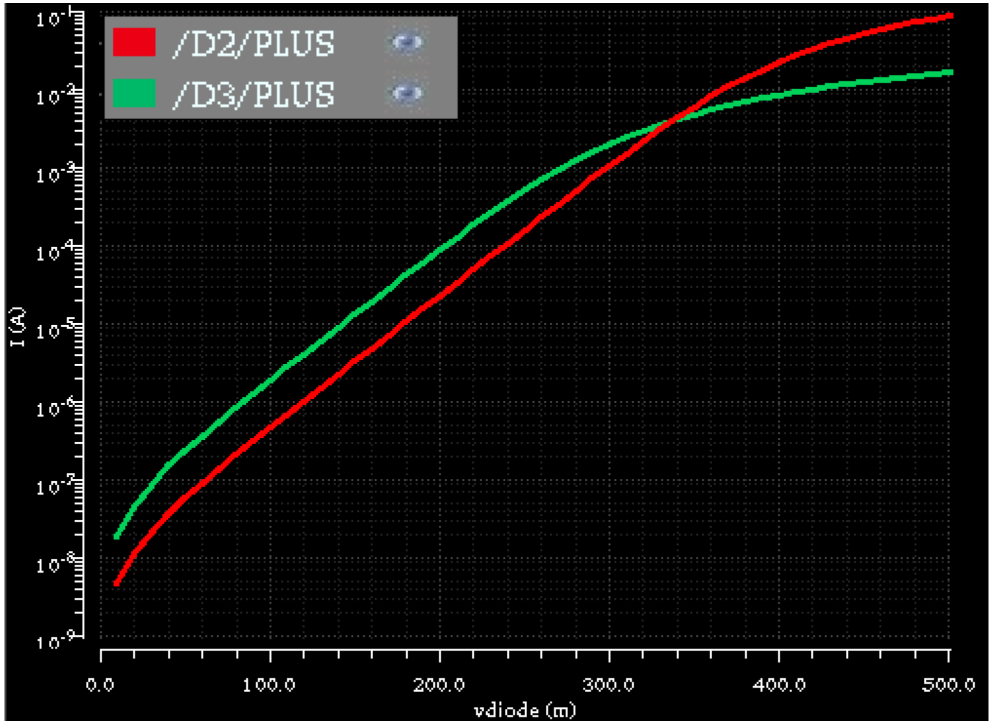
- ATTENTION / NOTE:
  - The simulator tries to be efficient and caches the models. If you just change `MyDiode.lib`, the change is not seen. There are (at least) 2 tricks to make sure the new model is used:
    - every time you change the model, use a *different model name* (and update the model name in the schematic)
    - Save `MyDiode.lib` under a *different file name* and include that new file in the model directory dialogue.

Solution 2

```
.MODEL diode1 d IS=1e-8 RS=1  CJ0=1e-11 VJ=0.7 M=0.5
.MODEL diode2 d IS=4e-8 RS=10 CJ0=1e-11 VJ=0.7 M=0.5
```

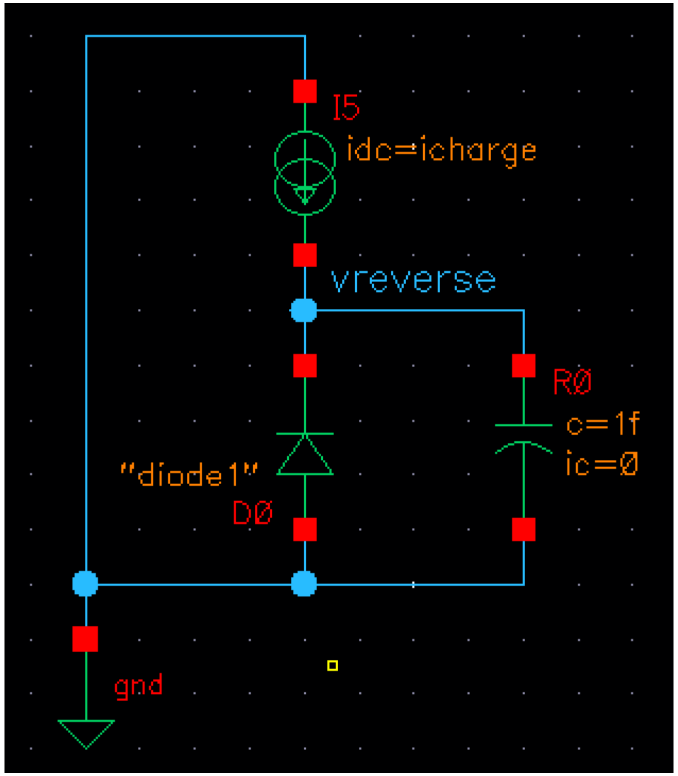


- D3 has more current at same voltage
- Large series resistor of D3 kicks in earlier



3. Capacitance

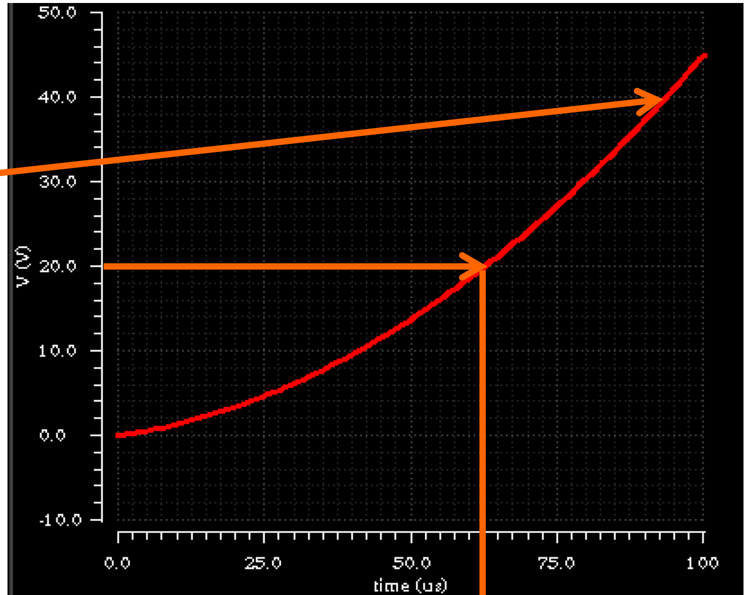
- To see the effect of the diode capacitance, you can charge it with a constant current *icharge*.
  - Make sure the polarity is such that the diode is in reverse bias
  - You can define the start voltage with a very small (1 fF) capacitor in parallel to the diode with an initial condition.



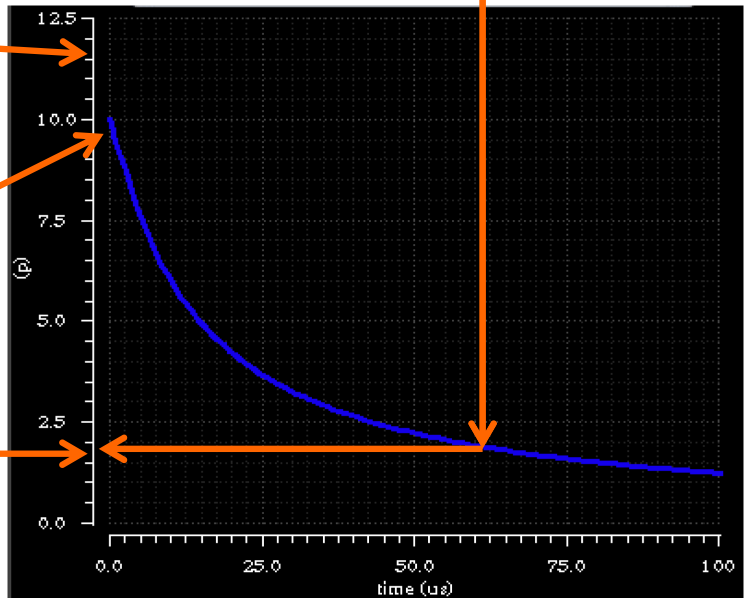
- Find a good value for *icharge* for your transient simulation
- Observe how the diode voltage increases with time. From the slope (calculator tool!), determine the capacitance
- Observe how the capacitance varies with voltage (time)
- Compare to what you expect from the model

Solution 3

- Charging with 1uA yields:
- The charging becomes *faster* for high voltages because capacitance *decreases*.



- Because dU/dt = I/C, Capacitance is C = I/(dU/dt) = 1uA/slope:

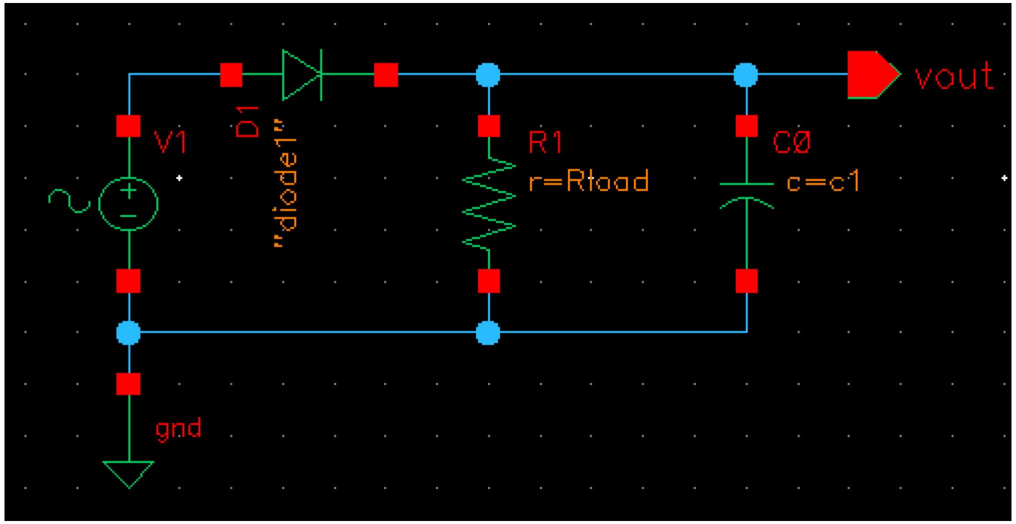


- Using C= $\mathbf{CJ0} \cdot \left(1 - \frac{U}{\mathbf{VJ}}\right)^{-\mathrm{M}}$ we expect
  - At U=0: C = C_{J0} = 10pF
  - At -20V: C = 10p $(1+20/0.7)^{-0.5}$ = 1.84pF

```
.MODEL diode1 d IS=1e-8 RS=1  CJ0=1e-11 VJ=0.7 M=0.5
.MODEL diode2 d IS=4e-8 RS=10 CJ0=1e-11 VJ=0.7 M=0.5
```

4: A Simple Rectifier

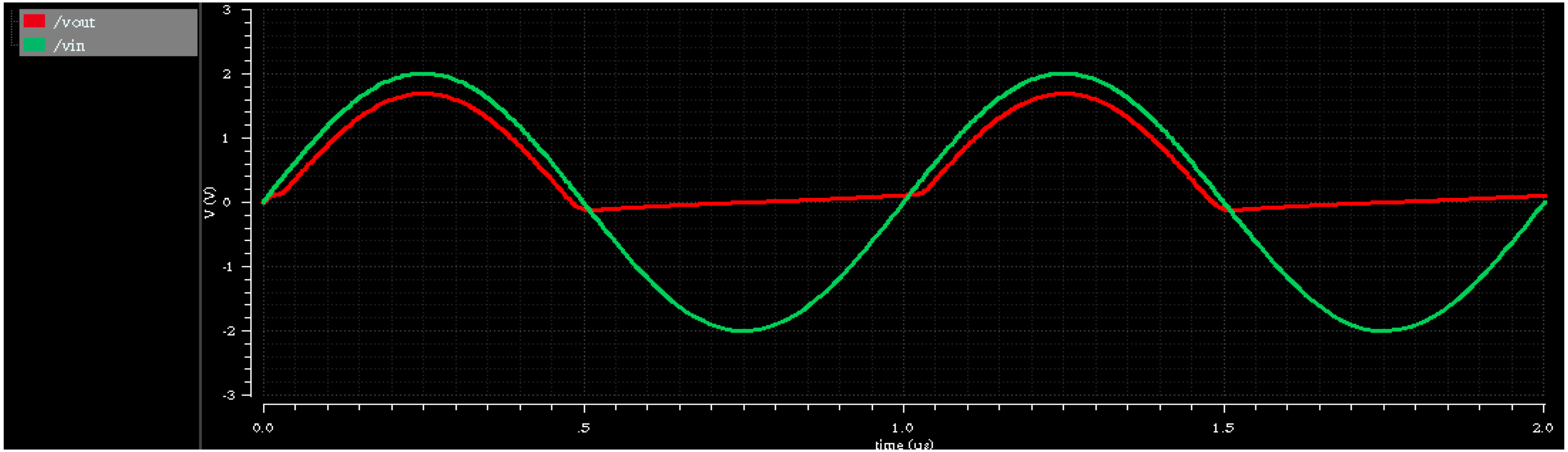
- Alternating voltages can be converted to ‘dc’ with a ‘rectifier’:



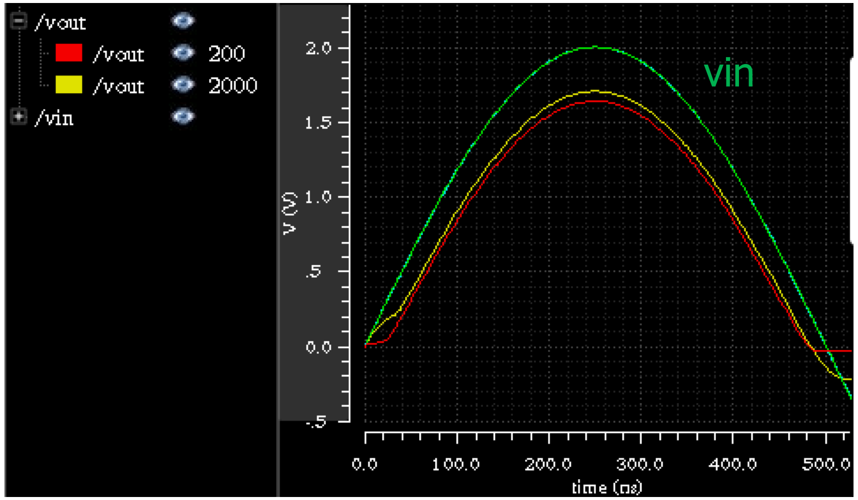
- Make a transient simulation (50 Hz, 10 V, R_{load}=1kΩ, C1=0)
  - Compare `vin` and `vout`. Observe the small difference in voltage. Where does it come from? How does that change with `Rload`?
  - Now set `C1` to 1 µF. Observe how `vout` stays positive even in the negative phases of `vin`. How does this work?
  - What are the effects of changing `Rload` and changing `c1`?
  - Which C is needed to keep V_{out} > 8V for R_{load}=1kΩ? Calculate!

Solution 4 (with different component values…)

- Using a 2V input at 1 MHz and R=1k, we get

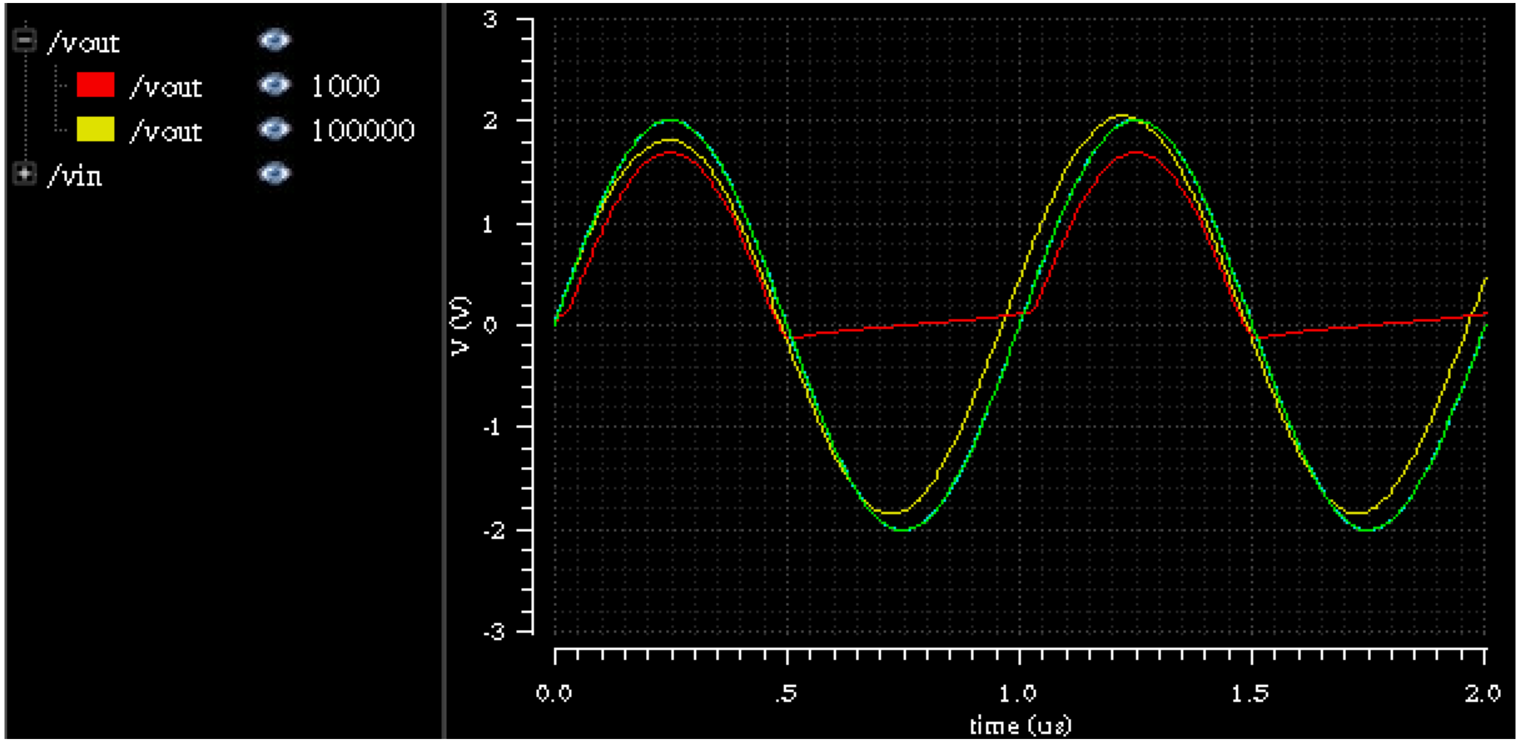


- The voltage difference is the forward diode voltage at the current the diode delivers. It is a bit more at high amplitudes (because current is higher)
- It is more for smaller R:



Solution 4:

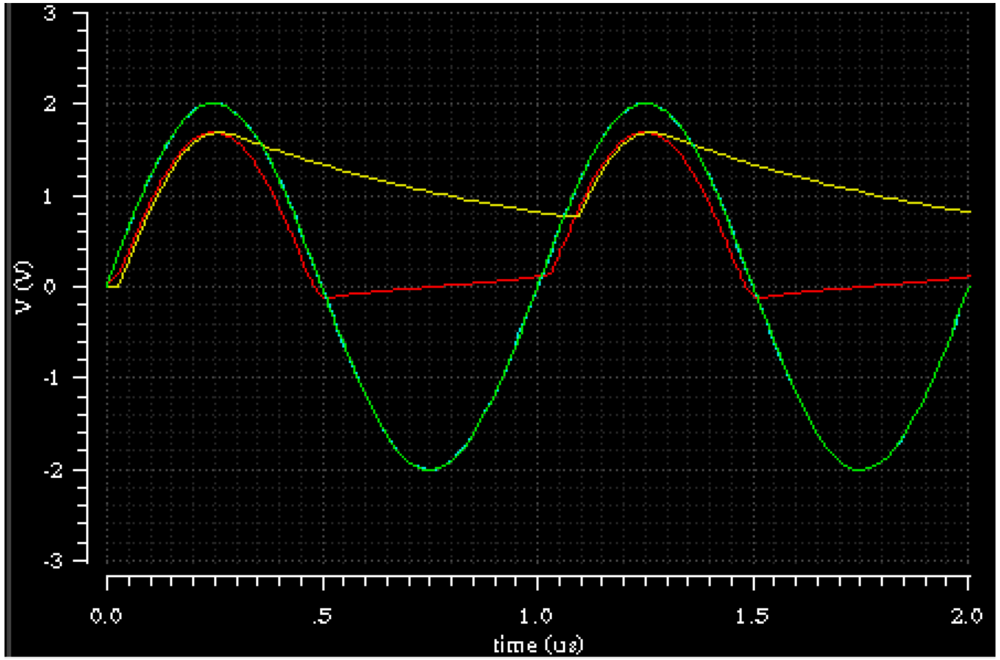
- Remark: for very high R, we see an unexpected result: The output follows the input:



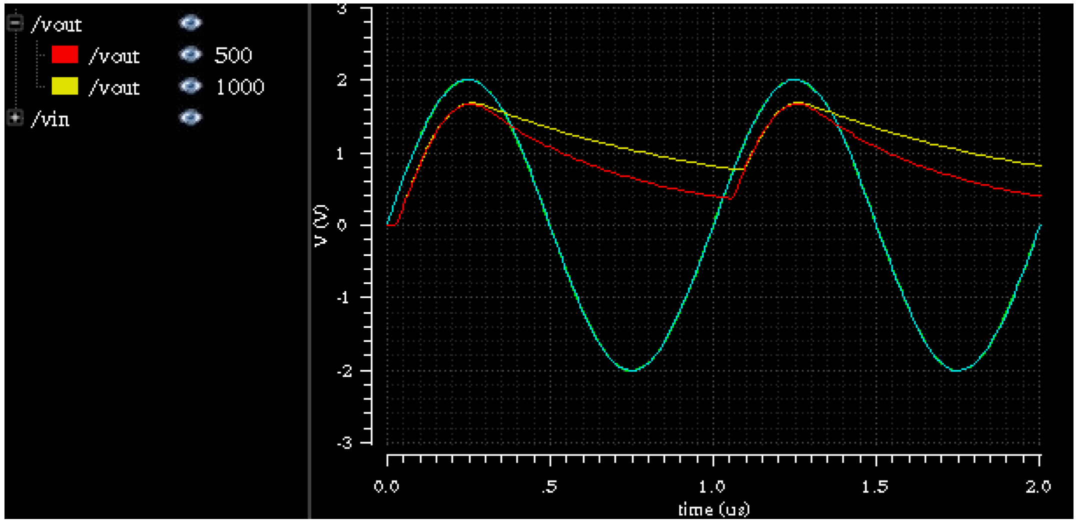
- How is that possible? -> This is due to the capacitance of the diode!!!!! This can be proven by running at a much lower sine frequency…

Solution 4

- Adding 0/1nF (R=1k):
- The positive half wave charges the cap. This then holds the output positive in the negative half wave. It is discharged by R.

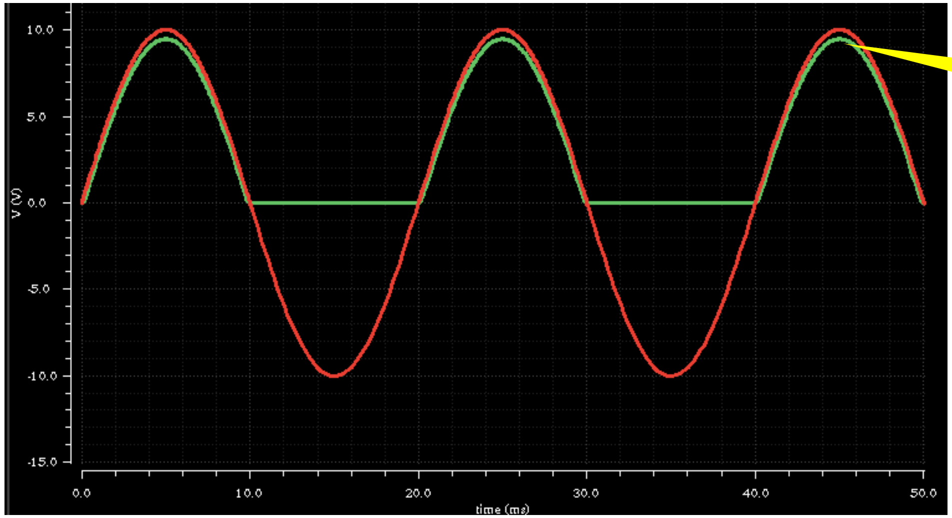


- Smaller R (C=1nF) discharges faster (R=500/1000):

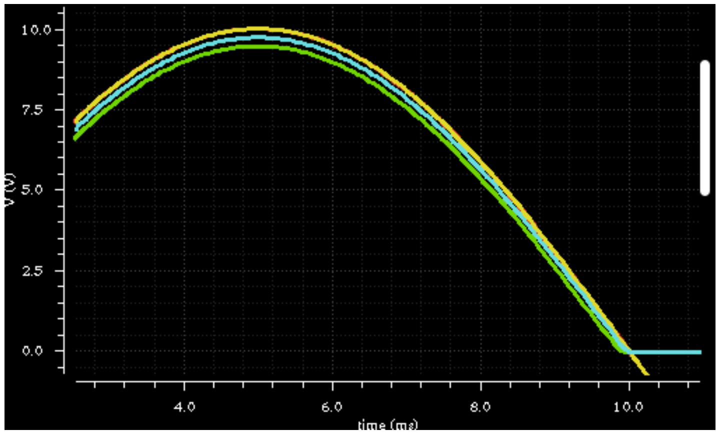


Solution 4 (with 50 Hz)

- The voltage at the resistor rises to ~10V. This leads to a current of ~10V/1k ~ 10mA. This current leads to a (nonlinear) drop on the diode

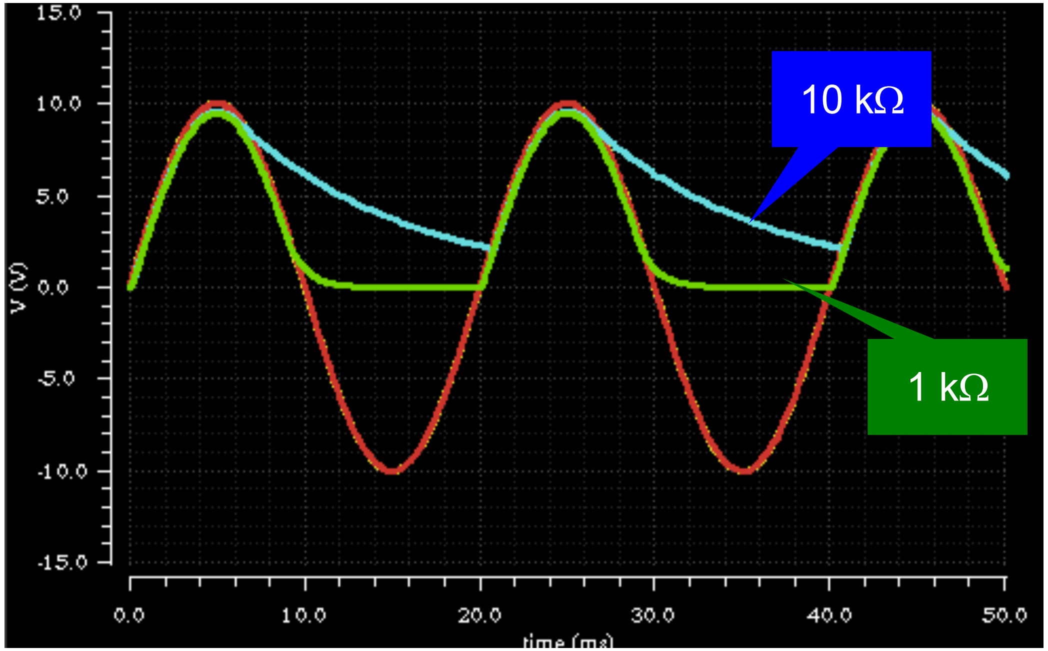


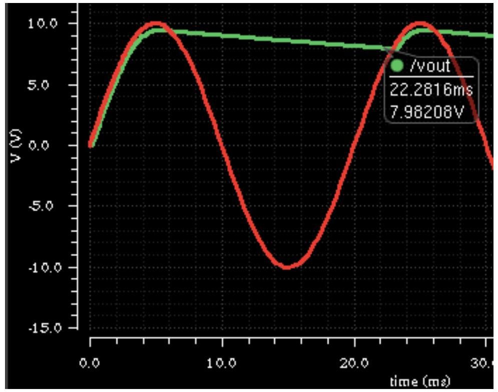
- At higher R, current is smaller and drop is smaller.



Solution 4 (50 Hz)

- The cap is charged and keeps the voltage at the output high.
- It is then discharged by R_{load} with time constant $\tau = R_{load}C$
- Discharge is slower for higher load resistors (and higher C).

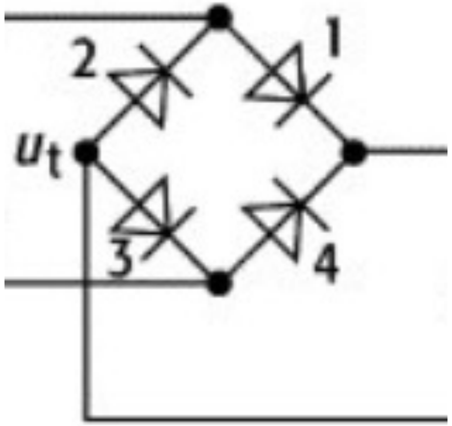


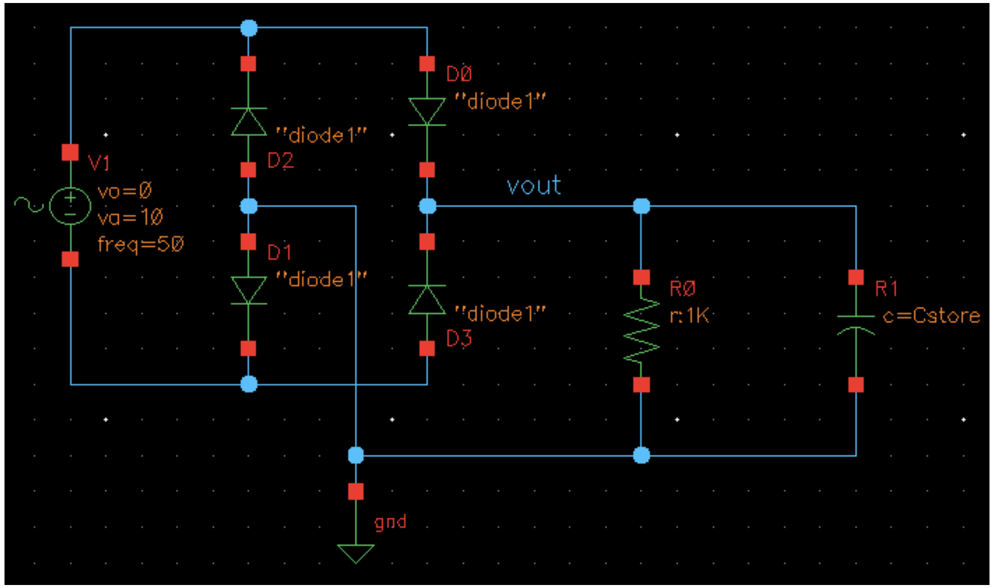


- Initial drop is dU/dT = I/C.
  This must be ~ 2V in 20ms to reach 8V.
  Therefore: C = I dT / dU = 10V / 1kΩ x 20ms / 2V = 100 uF

5: Full Wave Rectifier

- The full wave rectifier ('Graetz') uses 4 diodes to utilize the negative half-wave as well:
  - make a Schematic

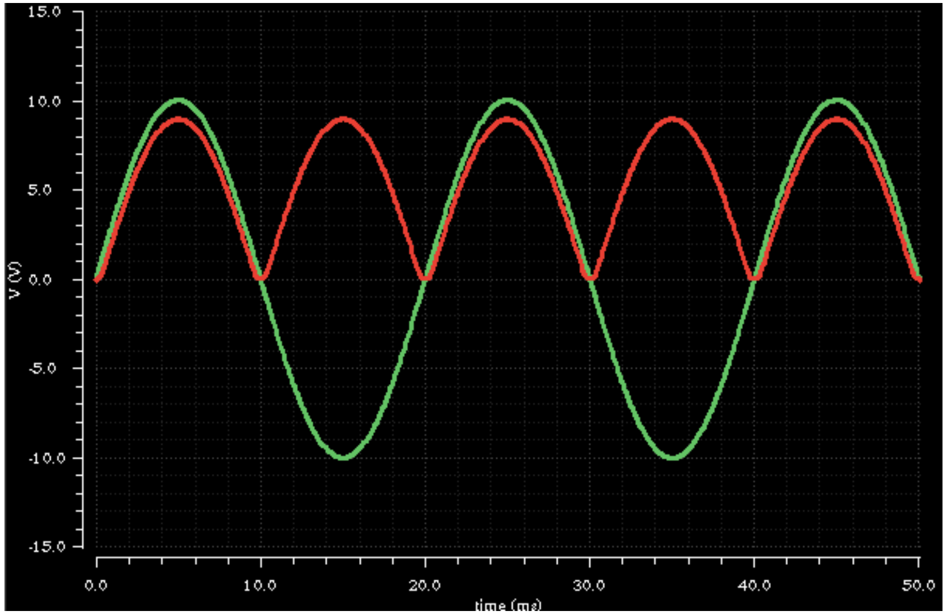


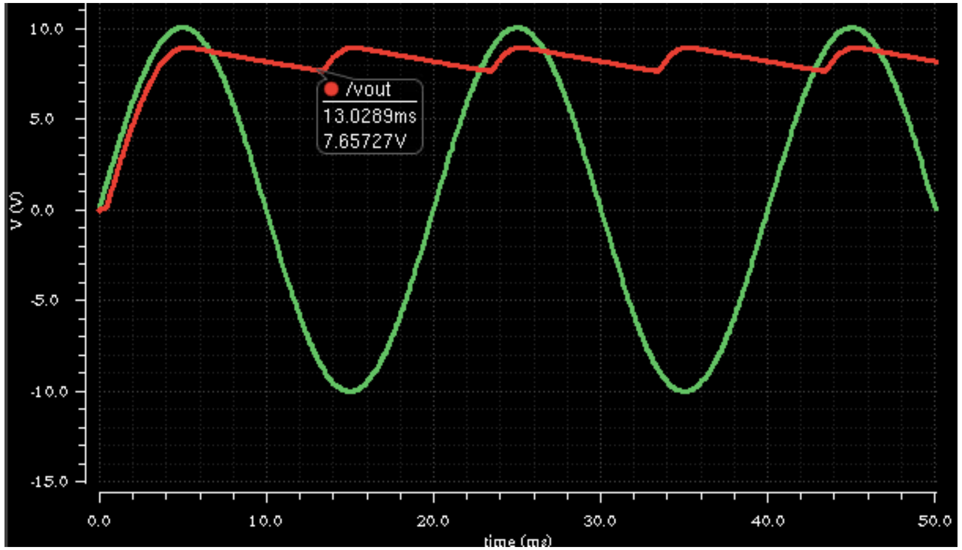


- How does V_{out} look like for C_{store} = 0
- How does the circuit work?
- What is the peak amplitude? Why?
- What C_{load} do you need to guarantee V_{out} > 8V? Calculate!

Solution 5

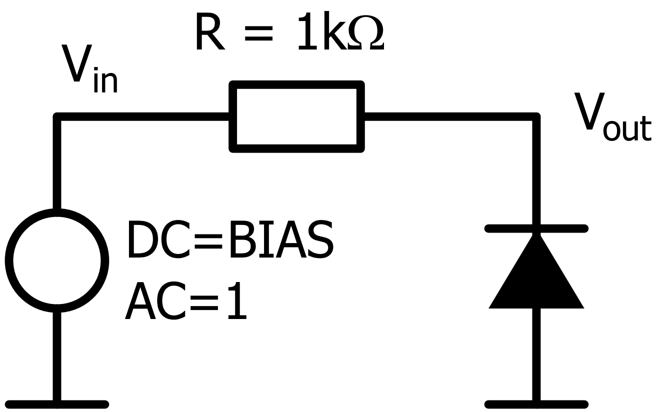
- The diodes provide a current path for both sine polarities.
- Two diodes in the path lead to twice the drop.
- Time is now half, so that half the cap is sufficient (50uF)





Exercise 6: Operation Point

- A voltage dependent capacitance is part of the diode model.
- Implement the following circuit:




```
.MODEL diode1 d
+IS=1e-08 RS=0.05 N=1.5 EG=0.6
+XTI=0.05 BV=50 IBV=5e-08 CJO=1e-11
+VJ=0.7 M=0.5 FC=0.5 TT=1e-09
```

- Make an AC sweep from 1M to 1G or so for BIAS = 1V
  - What is the corner frequency?
- Change BIAS to 10V or 0.5V
  - Does the corner frequency change?
  - Is it changing in the right 'direction'?

Solution 6

- Varying DC bias changes capacitance of the diode (higher reverse bias -> smaller capacitance)
- Therefore the corner frequency varies: