ECE 3040 Microelectronic Circuits

Exam 2

March 29, 2017

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Print your name clearly and largely: Soluxions

Instructions:
Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 new sheet of notes (1 page front and back), your note sheet from the previous exam as well as a calculator. **Turn in all note sheets with your exam.** There are 100 total points in this exam. Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I can not read it, it will be considered to be a wrong answer. Do all work on the paper provided and ***DO NOT SEPARATE THE EXAM PAGES***. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on <u>**ONE**</u> of the two following cases:

I DID NOT observe any ethical violations during this exam:

I observed an ethical violation during this exam:

First 20% **True /False and Multiple Choice - Select the most correct answer(s)**

1.) (2-points) True / False: The Base-Emitter junction of a BJT typically has a negligible amount of diffusion capacitance.

2.) (2-points) True / False: A BJT biased into saturation is the best bias mode for amplification.

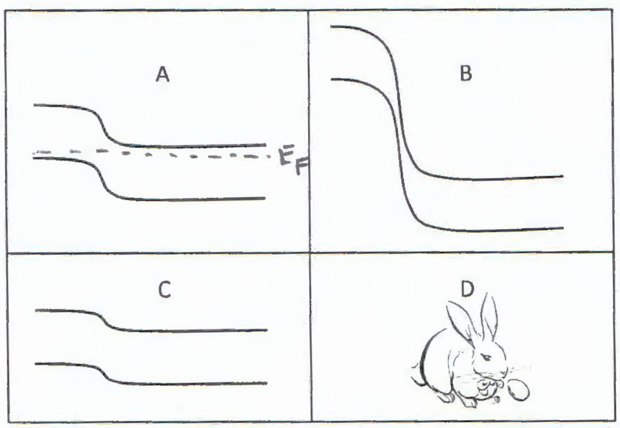
3.) (2-points) True / False: If a transistor has a finite Early voltage it also has an infinite output resistance, r_o.

4.) (2-points) True / False: In a BJT, the **MINORITY** carriers in the emitter are emitted into the base, and eventually come out the collector.

5.) (2-points) True / False: When 4 diodes are used as a full wave rectifier for use in an AC to DC converter, the output waveform should be integrated on a capacitor to smooth out the voltage ripples/humps.

6.) (2-points) True / False: A solar cell can be used as a photodiode simply by applying a constant reverse bias.

7.) (2-points) True / False: Tunneling is the mechanism where electrons jump across an energy barrier without the need to have enough energy to travel over the barrier.



8.) (2-points) For the above pictures of energy band diagrams, labeled A, B, C, and D, which of these pictures could represent an illuminated solar cell? Circle your answer:

A B C D

Both answers accepted since E_F line did not copy clearly

9.) (2-points) For the above pictures of energy band diagrams, labeled A, B, C, and D, which of these pictures indicate a diode not in reverse bias? Circle your answer:

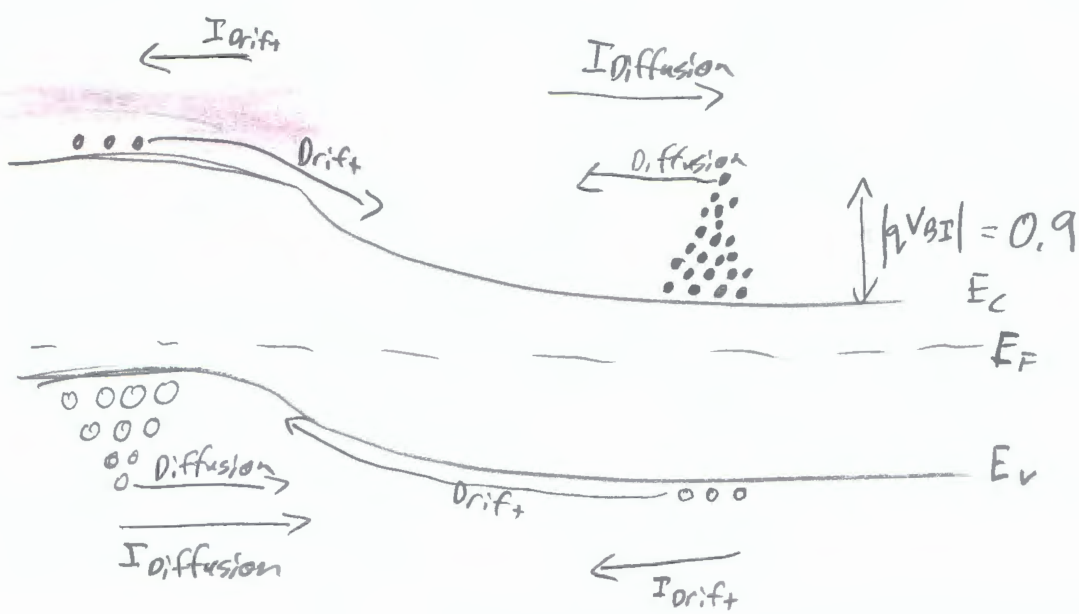
A B C D

10.) (2-points) For the above pictures of energy band diagrams, labeled A, B, C, and D, which of these pictures represents a cute fuzzy animal for democrats and a rapidly moving target for republicans? Circle your answer:

A B C D

11.) (20 points total in 2 parts)
Note: Neatness and clarity counts in the drawings for this problem.
All parts refer to a room temperature silicon pn diode to be used as a solar cell with a 0.9 volt built in potential and a 1.1 eV bandgap.

(a – 8 points) Draw the equilibrium energy band diagram, labeling the built in voltages and fermi level (do not calculate the fermi level – just sketch it).



(b – 8 points) On the same diagram from part a, indicate with open circles for holes and closed circles for electrons the magnitude of concentrations of both minority and majority carriers (example: more circles for larger concentrations) and the direction of carrier motion for both drift and diffusion currents. Check list of things to include on your diagram: 1) Drift hole current direction using arrows, 2) Diffusion hole current direction using arrows, 3) Drift electron current direction using arrows, 4) Diffusion electron current direction using arrows, 5) indicate electron and hole concentration magnitudes and carrier motion that lead to drift current and 6) indicate electron and hole concentration magnitudes and motion that lead to diffusion current. Your final drawing should look similar to one we described in class.

(c – 8 points) If the diode has an intrinsic concentration of $1x10^{10}$ cm^{-3}, a p-type doping concentration of $1x10^{15}$ cm^{-3}, and an n-type doping concentration of $1x10^{19}$ cm^{-3}, and generates 0.5 volts when illuminated, what are the excess electron and excess hole concentrations at the depletion region edges.

$$\Delta n(x=-x_p) = \frac{n_i^2}{N_A}\left(e^{qV_A/kT}-1\right) \qquad \Delta p = \frac{n_i^2}{N_d}\left(e^{qV_A/kT}-1\right)$$

$$\Delta n = \frac{10^{20}}{10^{15}}\left(e^{0.5/0.0259}-1\right) \qquad \Delta p = \frac{10^{20}}{10^{19}}\left(e^{0.5/0.0259}-1\right)$$

$$\boxed{\Delta n = 2.4e13\ cm^{-3}} \qquad \boxed{\Delta p = 2.4e9\ cm^{-3}}$$

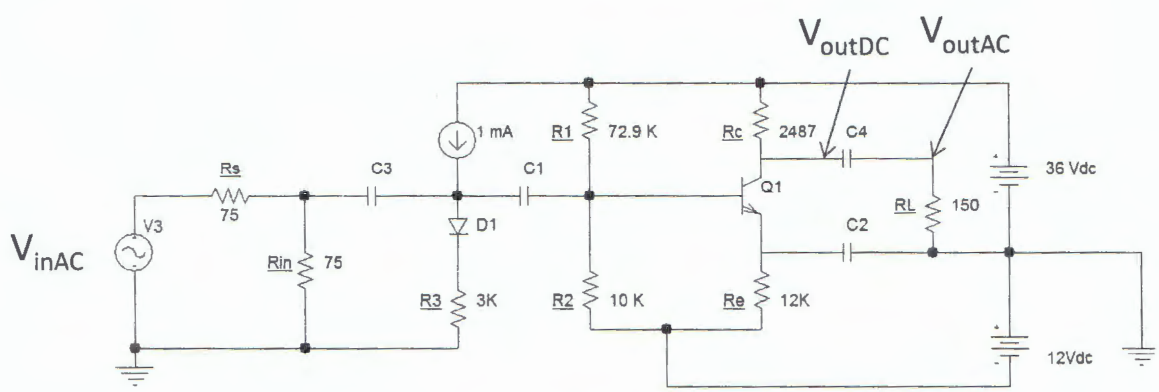
(d – 6 points) In one sentence (neatness counts), where does the photogenerated current come from? Be sure to indicate as part of your answer whether it is drift or diffusion current.

Electron - hole pairs ~~at~~ created by photo absorption enhance the minority carrier concentration leading to electron + hole seperation via enhanced drift current

13) **Pulling all the concepts together for a useful purpose:**
(50-points total: DC solution = 12 points, conversion to small signal model = 12 points, AC solution = 12 points and 4 points for accuracy of the graphs and 10 points for the solution of the clipped amplifier)

For the circuit below, you will be asked to solve for two cases:
Part A) The small signal gain of the amplifier, plot the small signal output waveforms AND
Part B) ALSO solve for a second case where the output is "overdriven", symmetrically clipped.

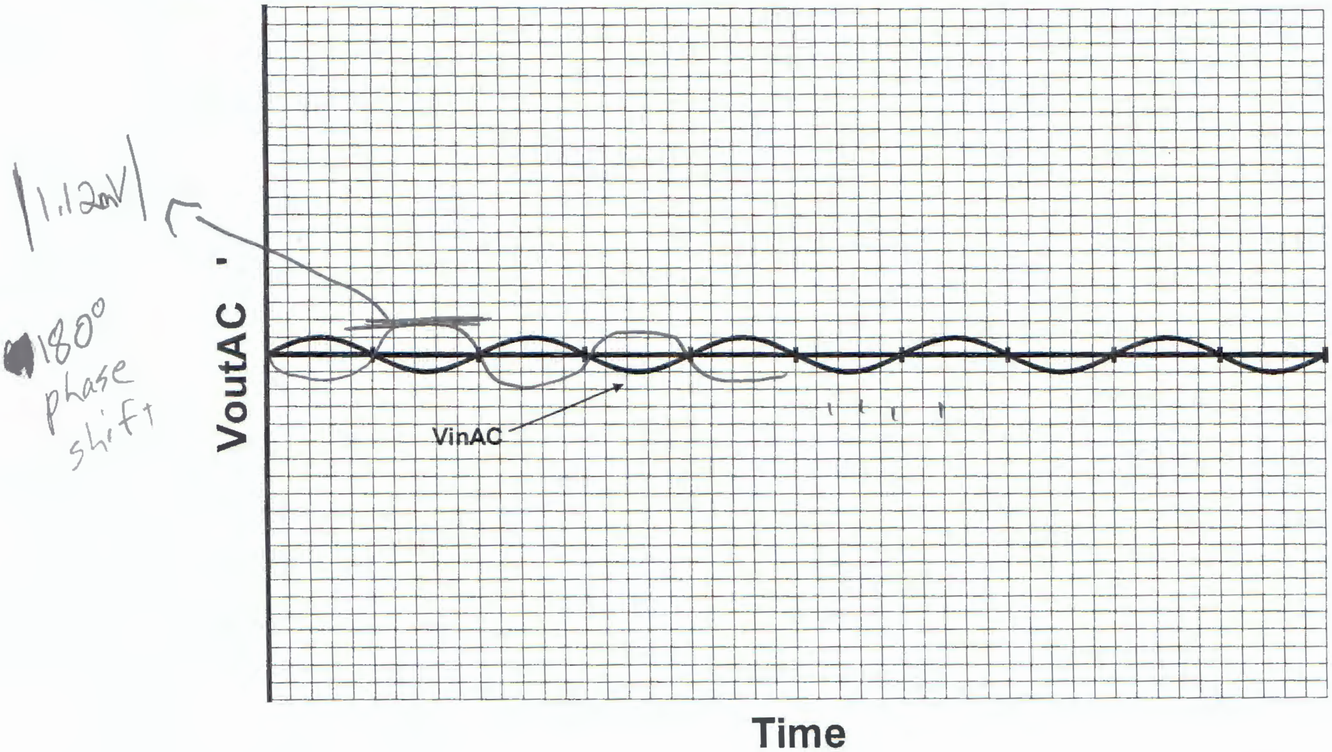
Q1: $V_{\text{Base-Emitter turn on}}$=0.7 V, $V_{\text{Base-Collector turn on}}$=0.5 V, β_{DC}=200, Early Voltage=21V
D1: $V_{\text{turn on}}$=0.7 V , Is=1e-12 amps
V_{inAC} = 1mV amplitude (i.e. 2mV peak to peak) at 1 KiloHertz

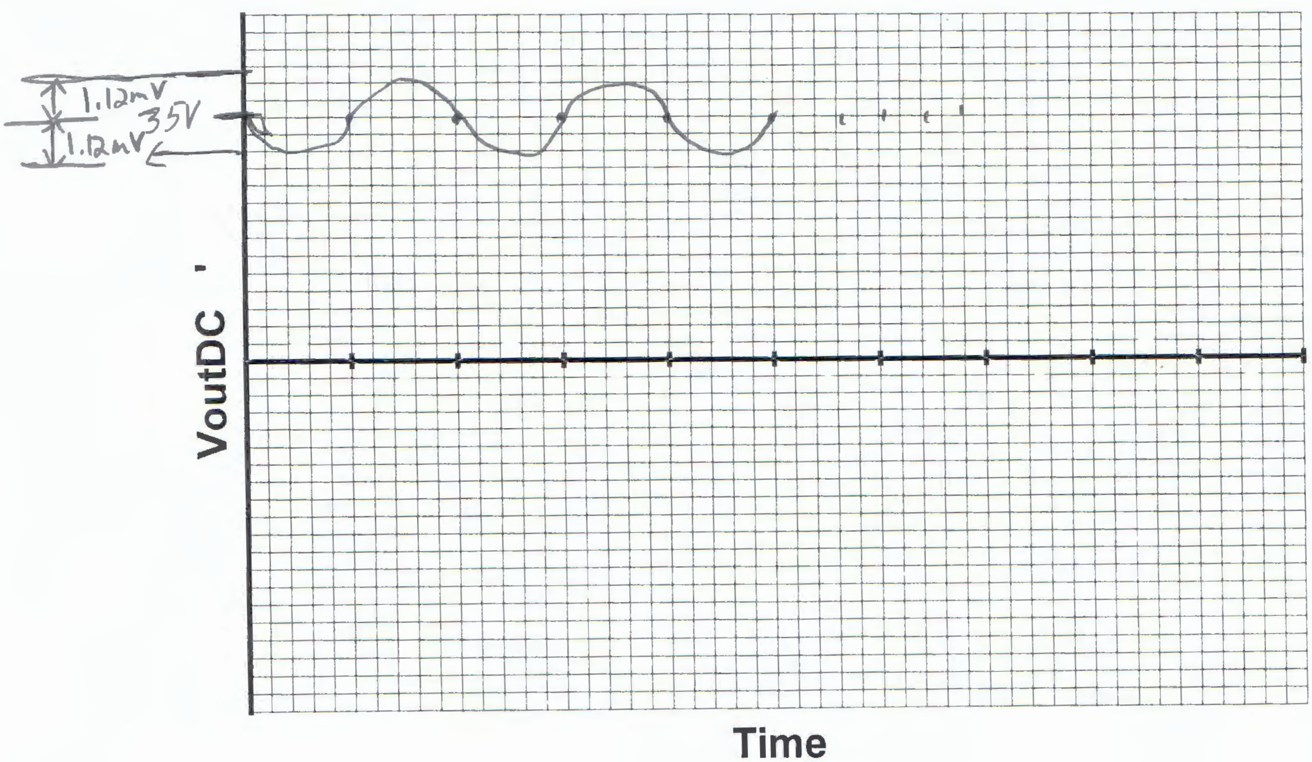


Part A) Given the above input voltage, V_{inAC}, sketch and accurately label a plot of the TWO output waveforms V_{outAC} and V_{outDC} <u>on the graph paper provided on the next page</u>. Assume the turn on voltages for all forward biased junctions are as described above. You may assume all capacitors are very large values and are thus, AC shorts and any inductors are very large values, and thus AC opens. Additionally consider the circuit to be operated at low frequencies where you can neglect all small signal capacitances of transistors and diodes. Also, neglect all resistances that result from quasi-neutral regions. **For full Credit, be sure to check your assumptions on the mode of operation of the transistor and to clearly label the axes of your plot.**

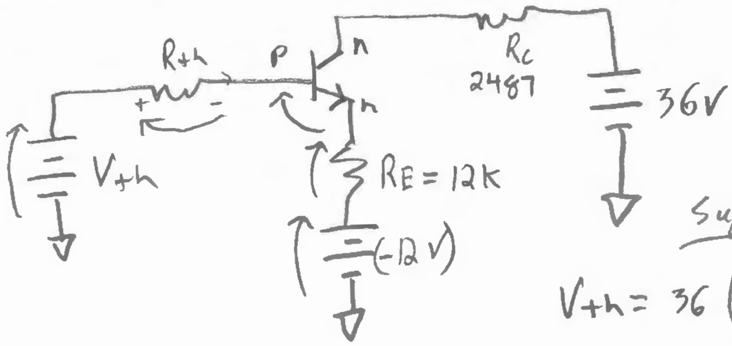
Part B) On the second set of graph paper, accurately plot and label (magnitudes) of the clipped waveform of an overdriven output at both V_{outDC} and V_{outAC}. **Again, for full Credit, be sure to clearly label the axes of your plot.**

Small Signal (not-clipped) answer Page





Extra work can be done here, but clearly indicate with problem you are solving.



$R_{th} = R_1 \| R_2 = 8.79K$

Superposition:

$$V_{th} = 36\left(\frac{10K}{82.9K}\right) + (-12)\left(\frac{72.9}{82.9K}\right)$$

$$= {}^{-}6.21V$$

$$(-12) + I_B(1+\beta)R_E + 0.7 + I_B R_{th} - \underset{(+6.2)}{(V_{th})} = 0$$

$$I_B = \frac{12 - 6.21 - 0.7}{(1+\beta)12K + 8.79K} = 2.1 \times 10^{-6} A$$

$I_B = 2.1\ \mu A$ $\quad I_C = \cancel{2.1 mA}\ 420\ \mu A$

$I_E = 422\ \mu A$

Check Assumptions: ✓

$V_C = 36 - (420\mu A)2487 = 34.955V$

$V_B = V_{th} - (2.1\mu A)(8.79k) = -6.228V$ FB

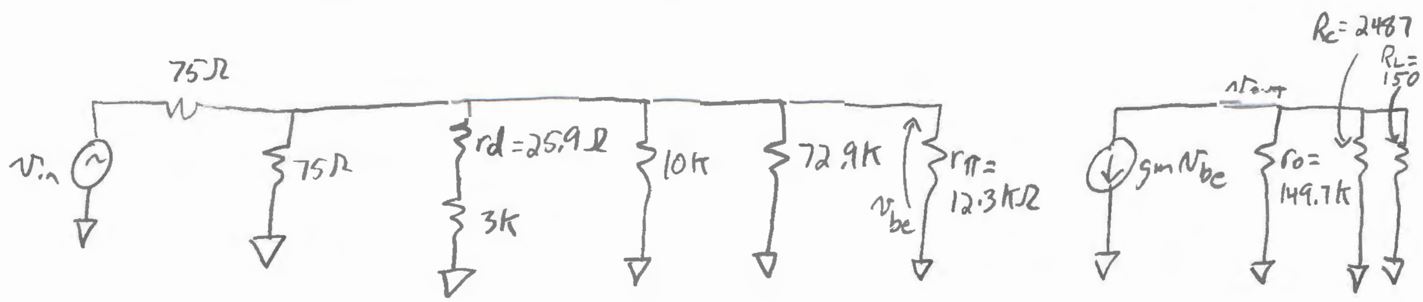
$V_E = -12 + (422\ \mu A)\ 12k = -6.936\ V$

RB

$$g_m = \frac{I_C}{V_T} = 0.01624\ S \qquad r\pi = \frac{\beta}{g_m} = \frac{200}{0.01624} = 12.3\ k\Omega$$

$$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{21 + (34.955 - -6.936)}{420\mu A} = 149.7\ k\Omega$$

$$r_d = \frac{V_T}{I_D + I_S} = \frac{0.0259}{0.001 + 1e{-}12} = 25.9\ \Omega$$



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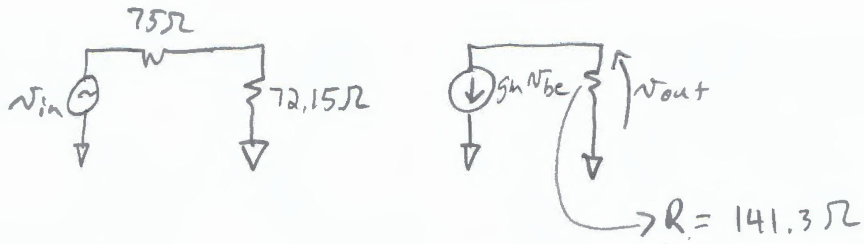


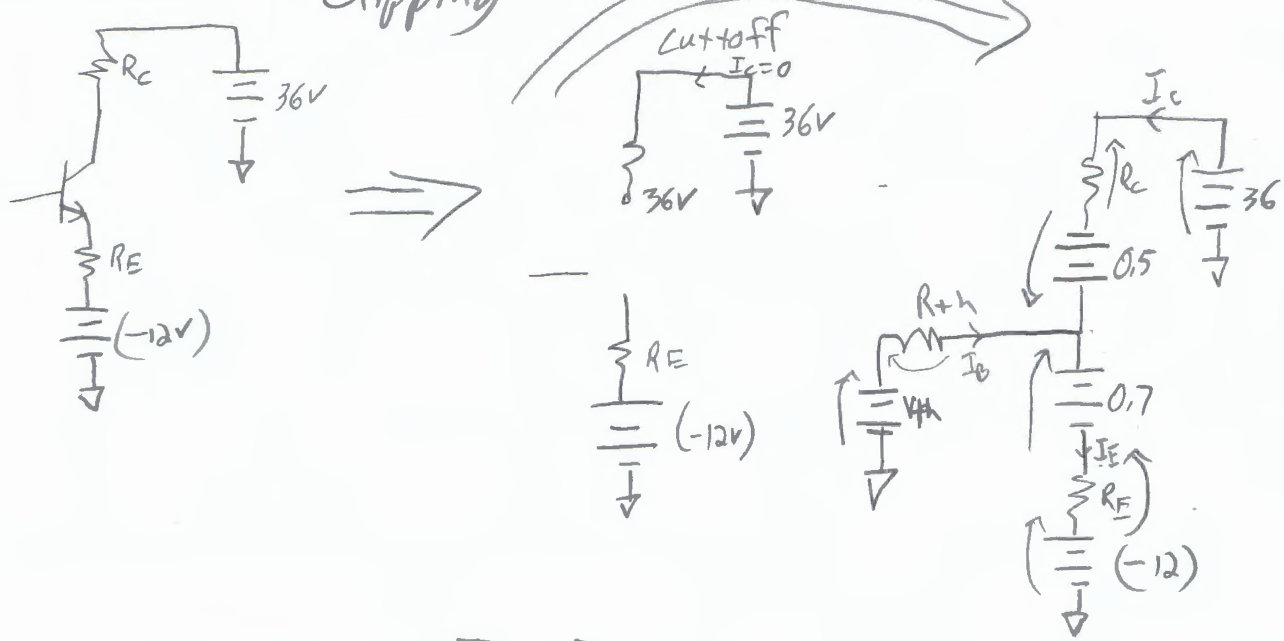
$$\frac{v_{out}}{v_{be}} = -g_m R = -2.29 \text{ V/V}$$

$$\frac{v_{be}}{v_{in}} = \frac{72.15}{72.15+75} = 0.49 \text{ V/V}$$

$$\frac{v_{out}}{v_{in}} = \left(\frac{v_{be}}{v_{in}}\right)\left(\frac{v_{out}}{v_{be}}\right) = -1.12 \text{ V/V}$$

Video "Buffer" Amplifier

Clipping



Approximate $I_C \approx I_E$

$0 = 36 - I_C(R_C + R_E) + 0.5 - 0.7 + 12$

$I_C = \frac{47.8}{10K + 2487} = 3.82\text{mA}$

$V_C = 36 - I_C(R_C) = 26.47\text{V}$

Overdriven (Clipped) answer Page