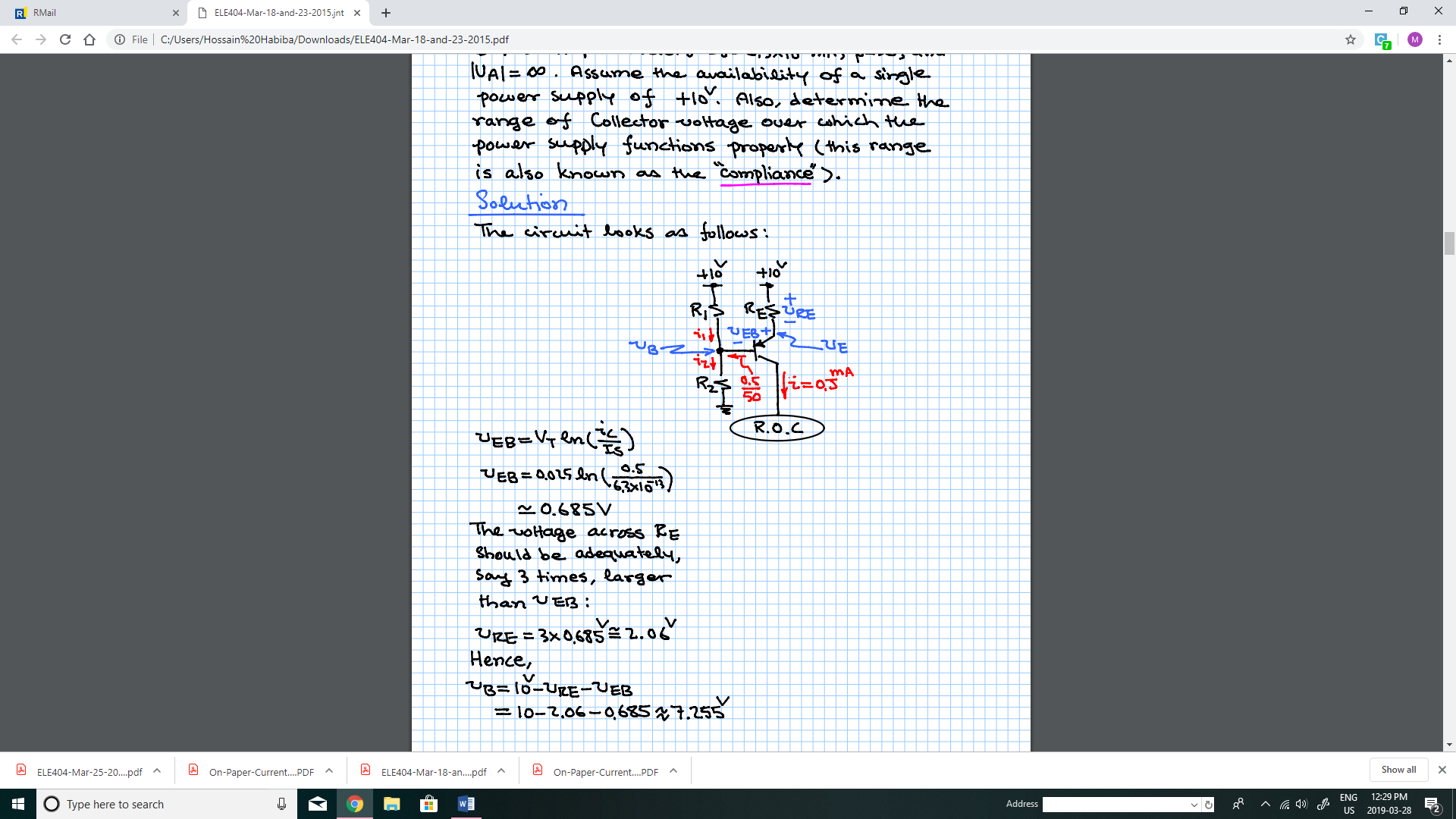
**Problem Set**

**Current Sources and Current Sinks:**

**Q1.**

Design a 0.5-mA current source that uses a BJT with parameters , and . Assume the availability of a single power supply of +10V. Also, determine the range of collector voltage over which the power supply functions properly with ignoring the Early effect (this range is also known as the ‘compliance’). Calculate the output (or internal) resistance of this current source and the small-signal gain (collector current change for a collector voltage change.).



**Solution:**

The circuit looks as follows:

The voltage across should be adequately, say 3 times, larger than :

Hence,

Ignoring , one finds

Then let

Also,

Hence,

The collector voltage range can be calculated as follows:

That is, the current source maintains a constant current of 0.5 mA so long as the collector voltage, which depends on the rest of the circuit (R.O.C), remains below 7.64V.

**Output Resistance:**

Small-signal gain

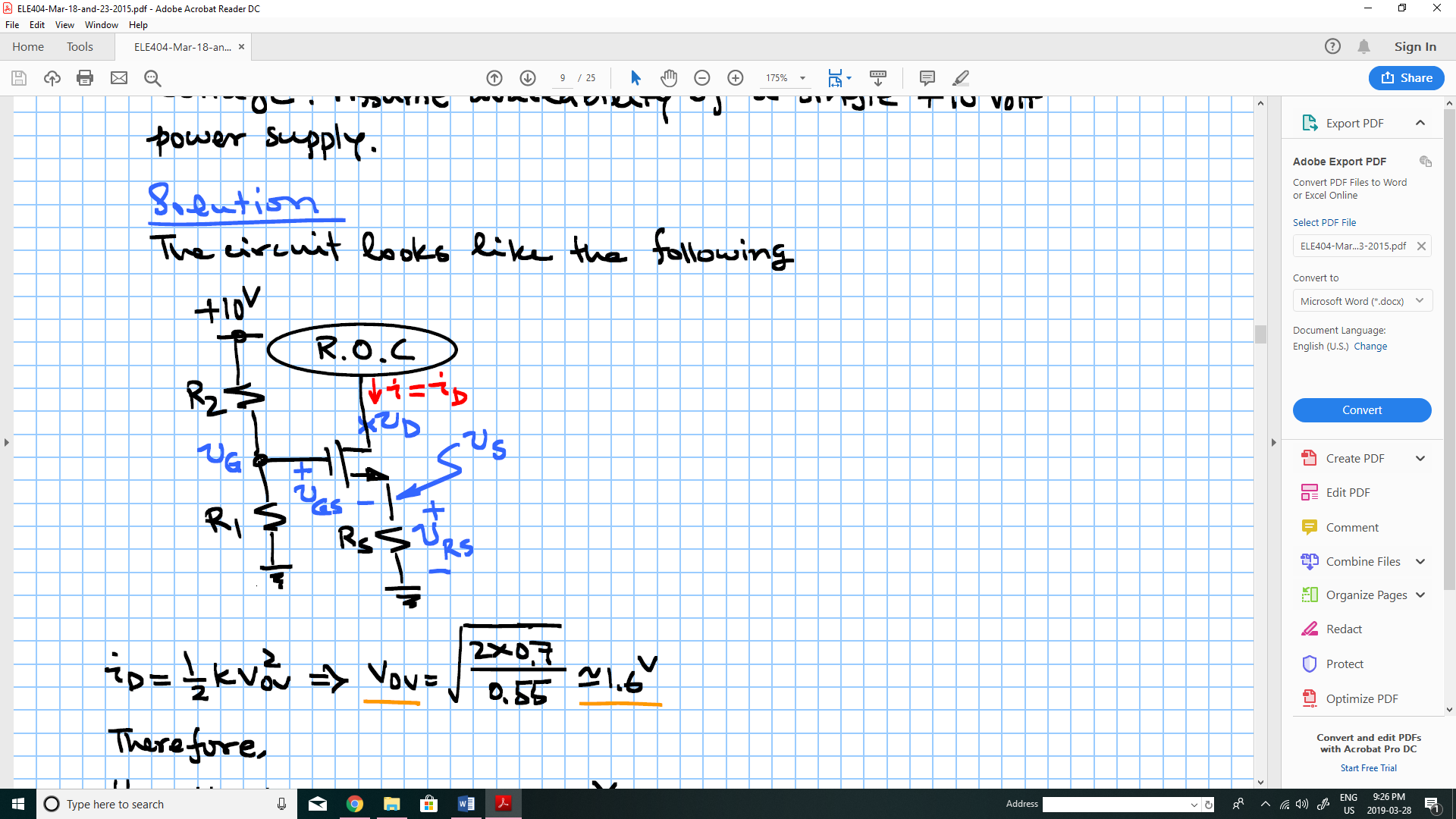
**Q2.**

Redesign the above circuit replacing the resistance with a Zener diode of voltage 4.7V, and . Also calculate the current ripple with assuming a supply voltage ripple of 1.0V peak-to-peak.

**Q3.**

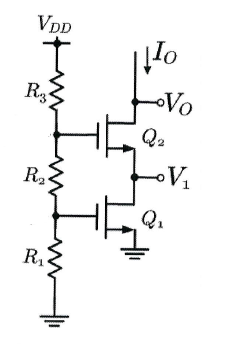
Design a 0.7-mA current sink using a MOSFET with the parameters , and . Assume the availability of a single +10V power supply.

1. Determine the permissible range of the Drain voltage. Ignore the channel-length modulation effect (or Early effect).
2. Calculate the current ripple with assuming a supply voltage ripple of 1.0V peak-to-peak.
3. Find the output resistance.
4. Redesign the circuit replacing the resistance with a Zener diode of voltage 4.7V, and . Also calculate the current ripple with assuming a supply voltage ripple of 1.0V peak-to-peak.



**Q4.**

In the cascade current sink shown in Figure, the MOS devices have the parameters , and ; the resistors have the values and the power supply voltage is Ignoring the Early effect, calculate the output current , the voltage and the minimum permissible value of the output voltage . Also, calculate the output (or internal) resistance of this current sink and the small-signal gain .

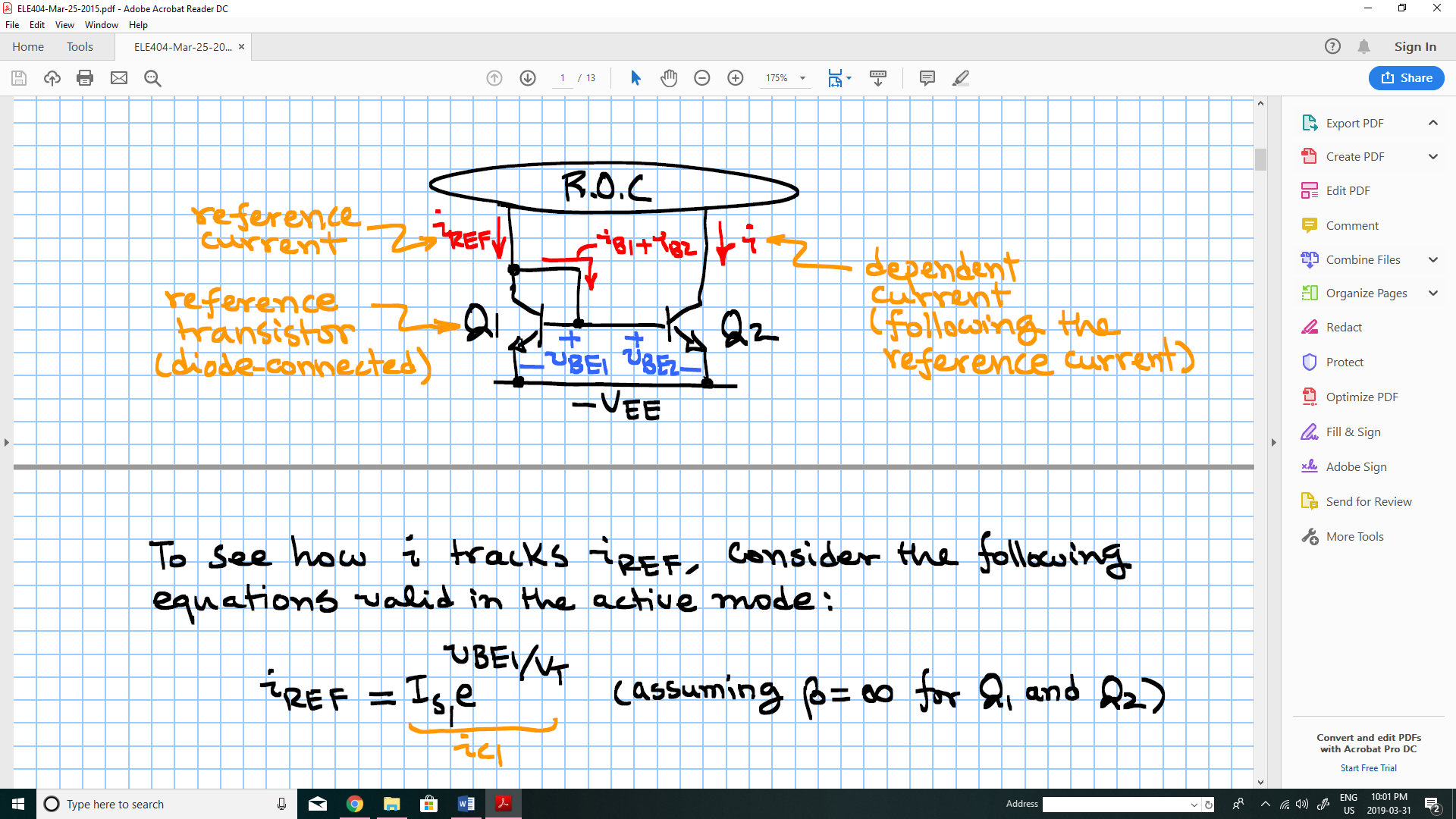


**Current Mirrors**

Sometimes one needs to impose a current on a circuit branch that is a scaled replica of the current in another circuit branch. In other words, one may need a current-controlled dependent current source. Such a dependent current source is referred to as a “current mirror”.

One prominent application of a current mirror is in differential amplifiers when one wants to single-ended output, but does not want to lose half of the gain.

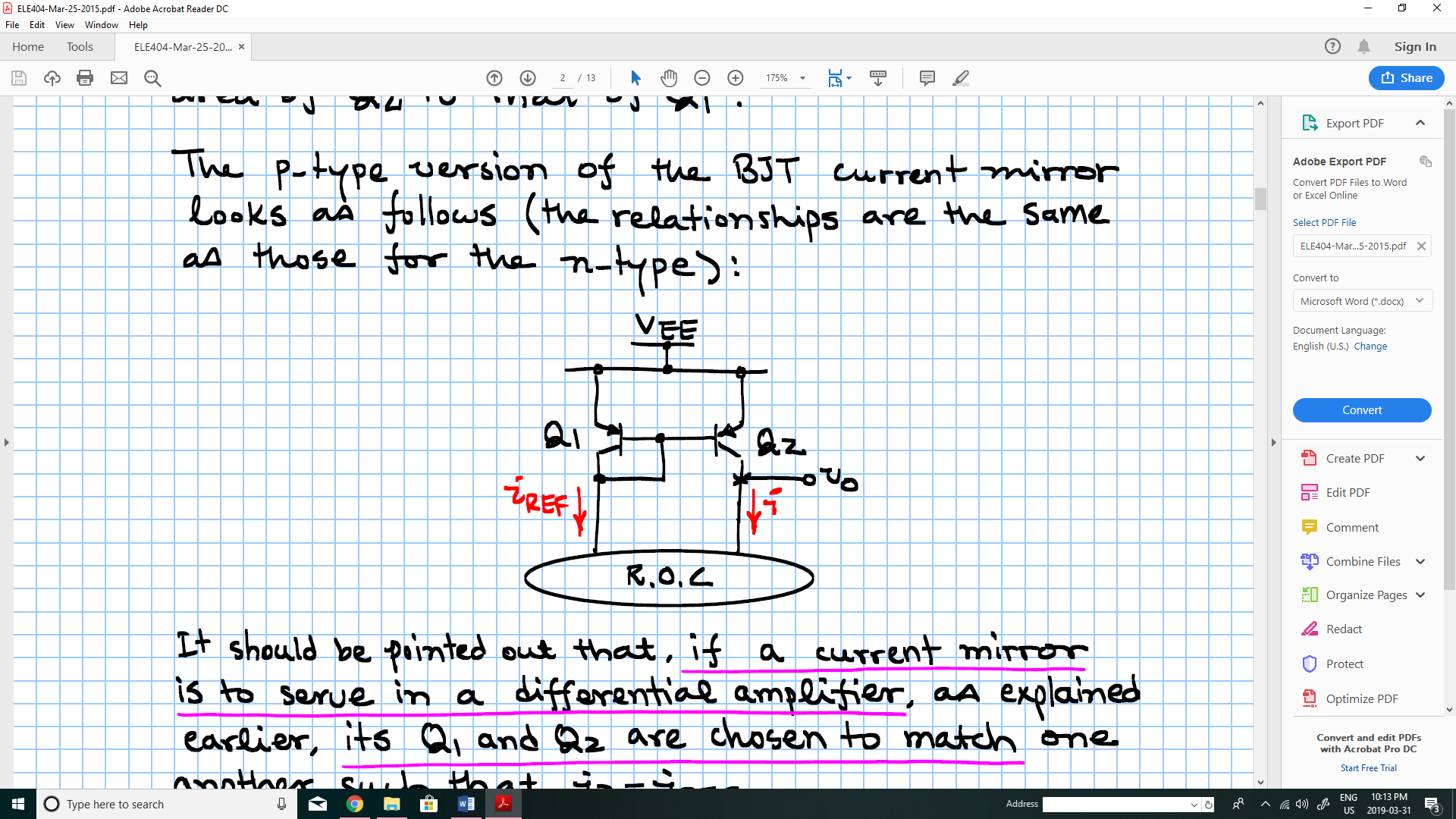
The following circuit is an n-type BJT current mirror in which the current tracks (i.e. is a scaled replica of) the reference current , provided that is in the active mode. Transistor is so-called diode-connected transistor and in the active mode anyways.



Assuming for Q1 and Q2

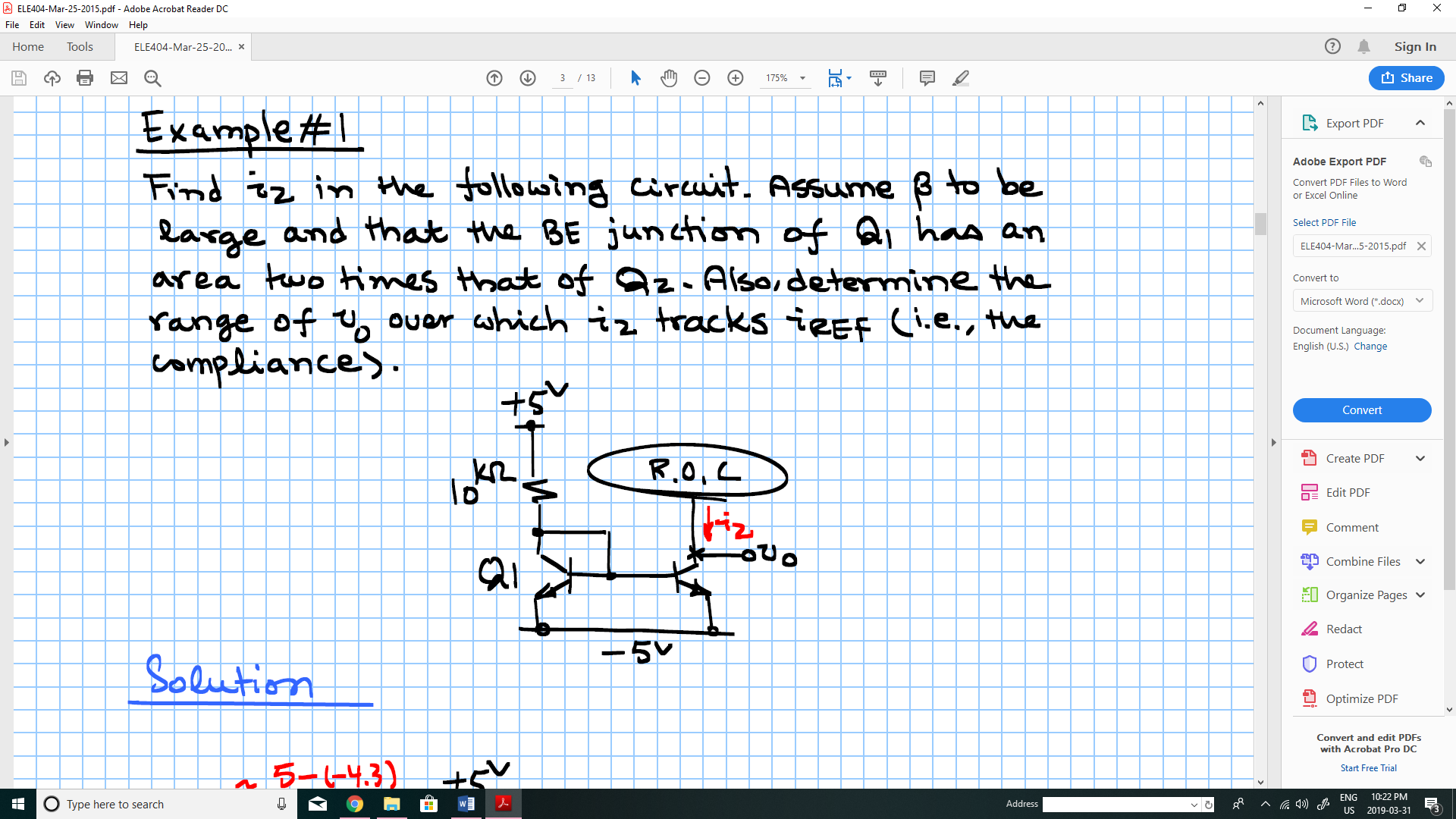
By KVL,

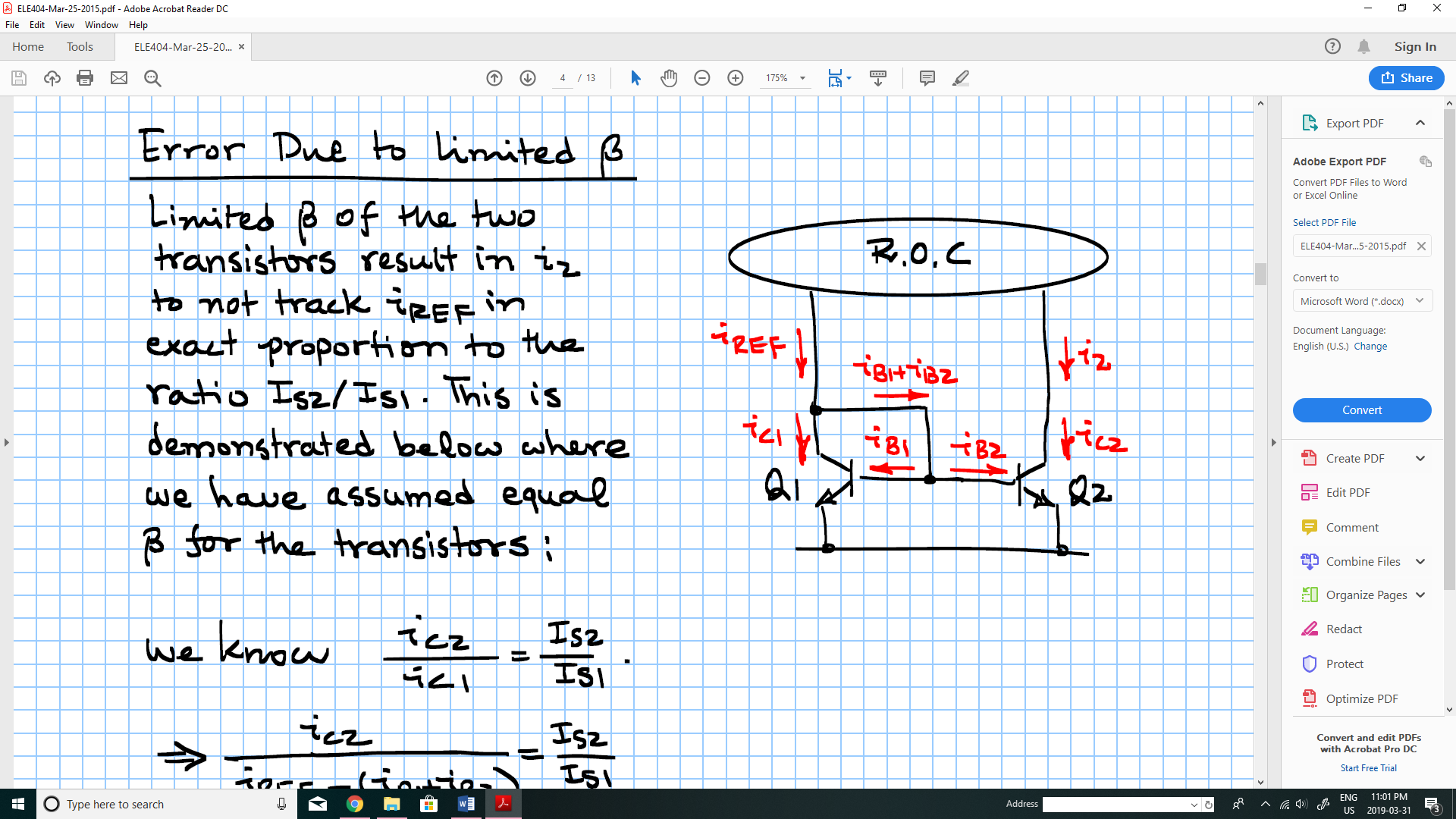
Current mirror using p-type BJTs,



If Q1 and Q2 are matched in current mirror circuit (while used in differential amplifier), the current .

**Example#1**

Find in the following circuit. Assume to be large and that the BE junction of has an area two times that of . Also, determine the range of over which tracks (i.e. the compliance).

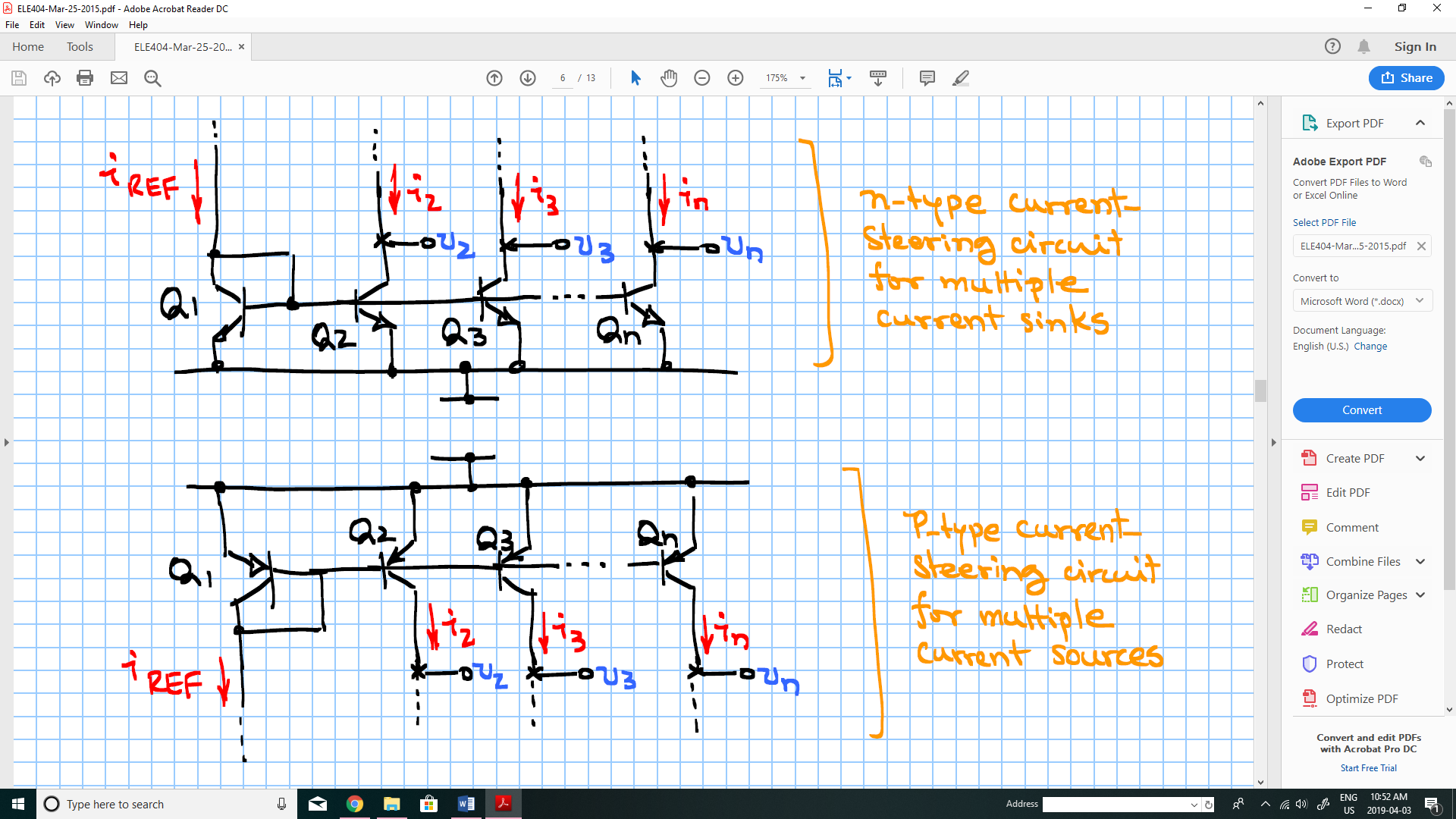
**Error due to limited (i.e. )**

**Example#2**

Repeat Example#1 if for the two transistors.

**Current-Steering Circuits**

Integrated-circuits (ICs), including integrated multi-stage amplifiers (such as OP-Amps), use multiple current sources/sinks which can be conveniently produced as scaled copies of a reference current by a current-steering circuit. Current-steering circuits are extended current mirrors, as shown in the following two diagrams:



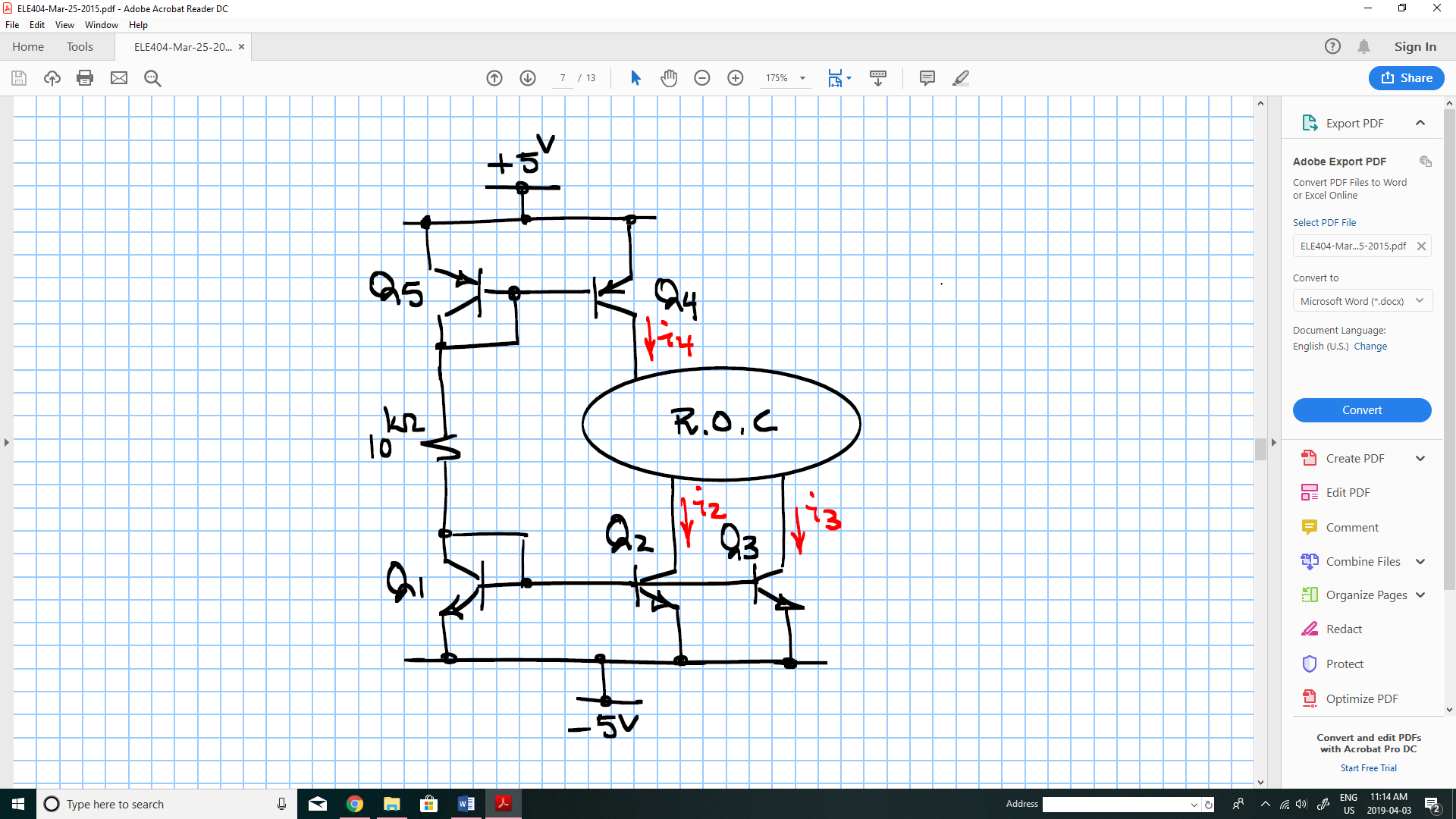
It is an easy matter to show that, assuming .

(By properly sizing the cross-sectional junction areas of the transistors, the designer sets the currents to have the desired values, relative to ).

Combining an n-type current steering circuit with a p-type current-steering circuit, one can produce multiple current sources and current sinks from one reference current.

**Example#3**

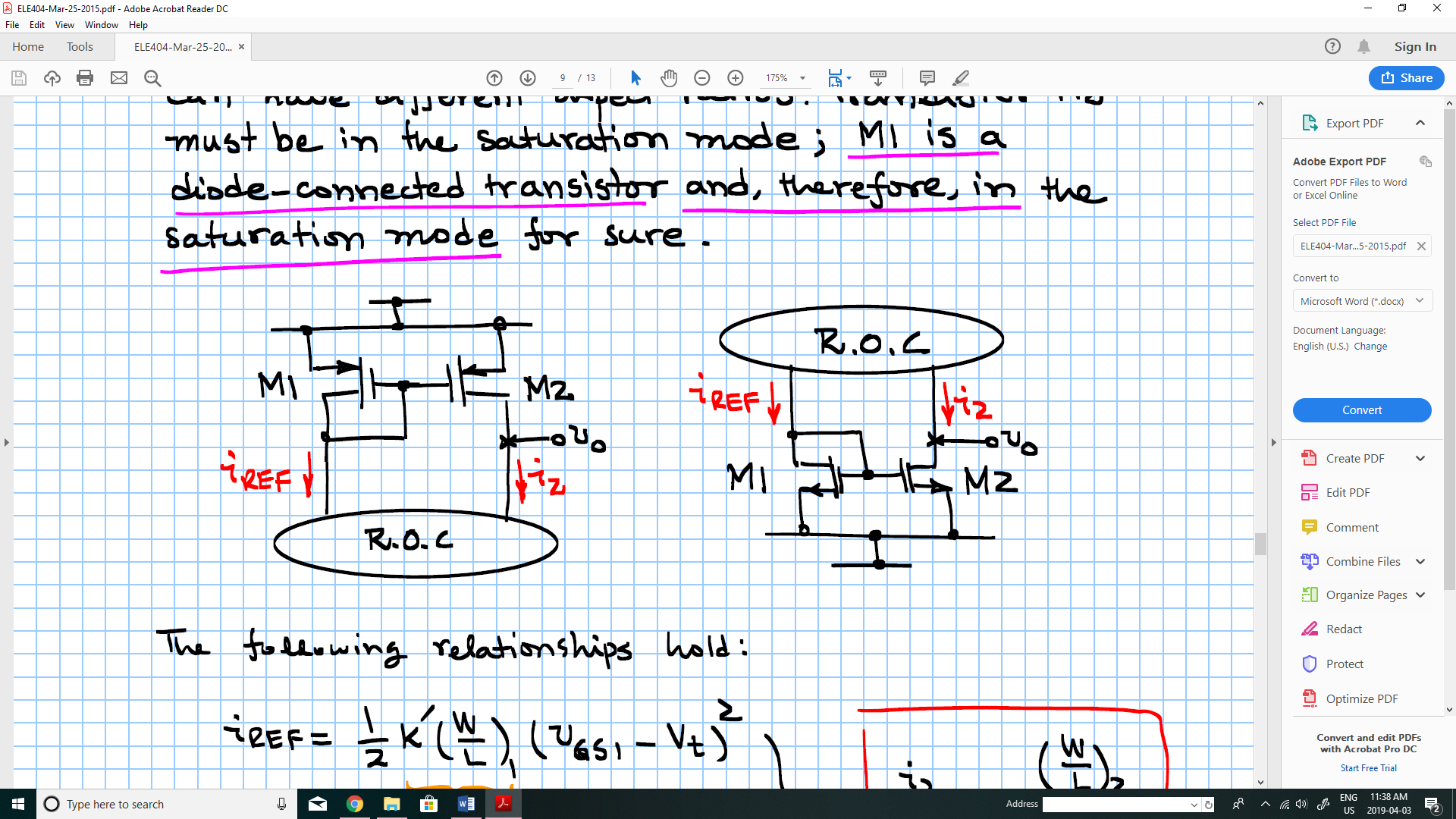
Determine and in the following circuit, assuming large and negligible Early effect for the transistors. All transistors are identical except and that have twice the BE junction area.



**MOS Current Mirrors and Current-Steering Circuits**

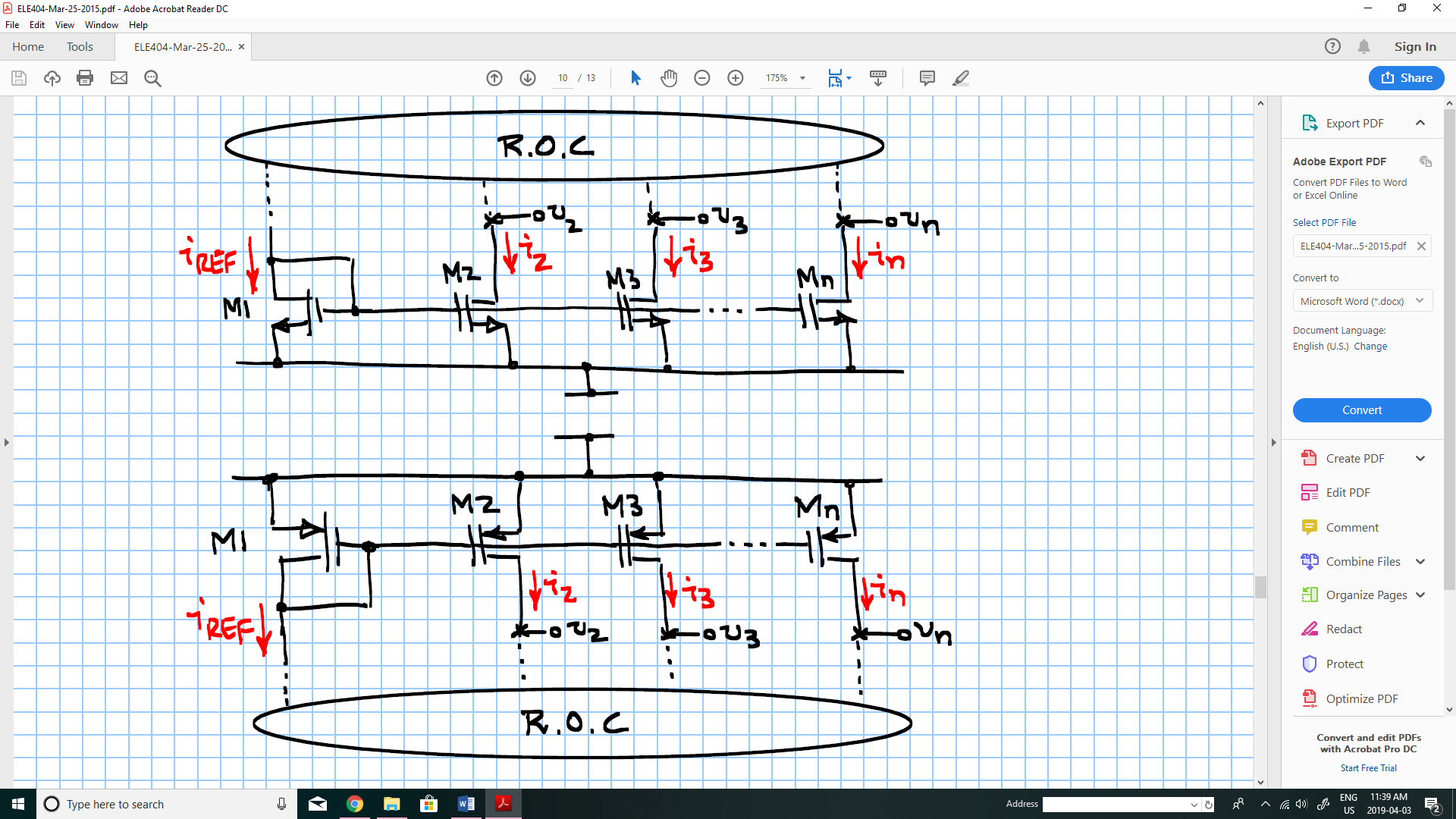
MOS current Mirrors are shown below. Transistor M1 is diode current and, therefore, in the saturation mode for sure. Transistor M2 must be in the saturation mode.

As



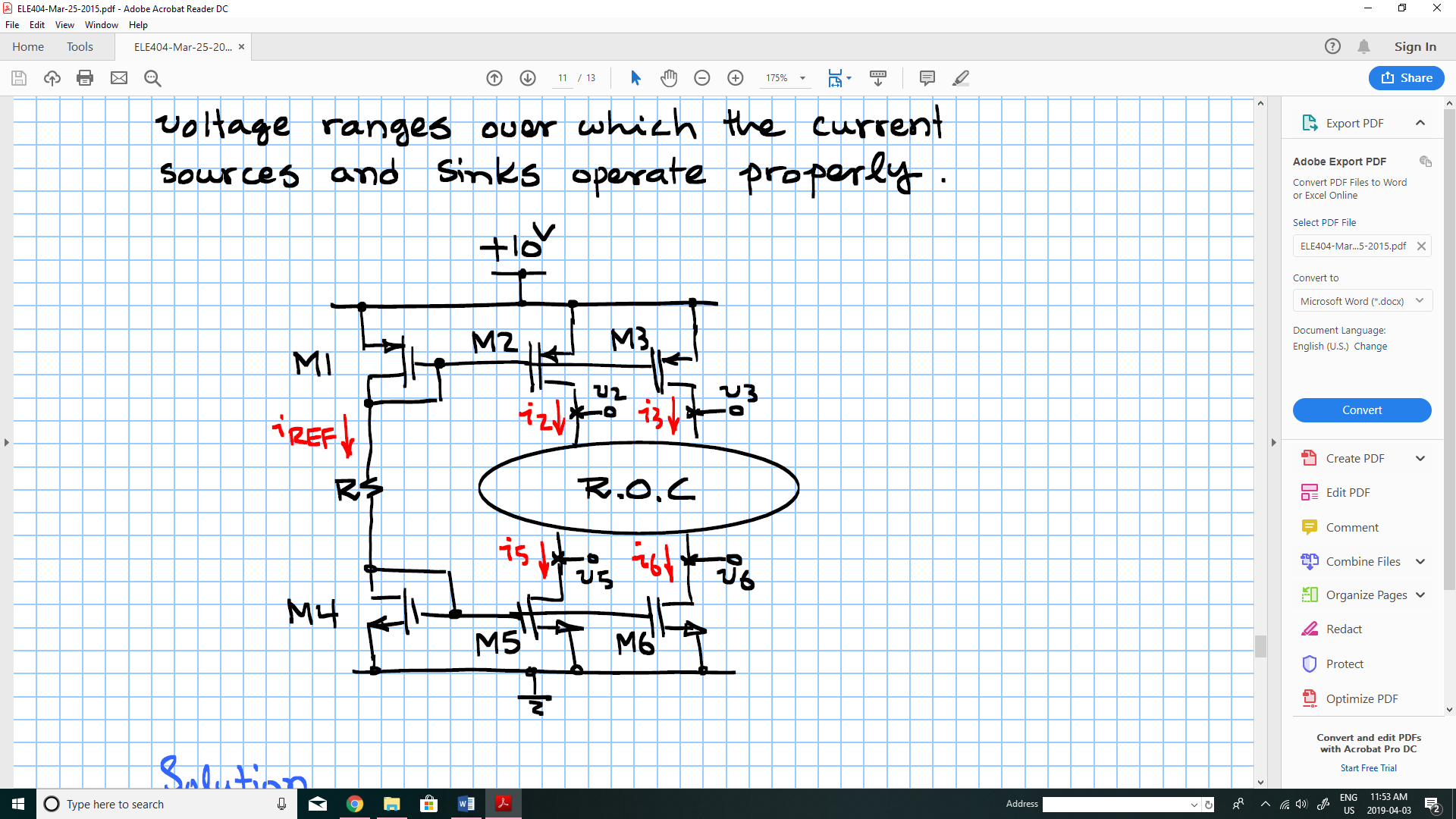
For identical transistors, , then ; which is the current mirror used in the differential amplifiers.

**MOS Current-Steering Circuits:**



**Example #4:**

For the following circuit, and . Also Determine such that . Then, find the other currents. Also, calculate the voltage ranges over which the current sources and sinks operate properly.

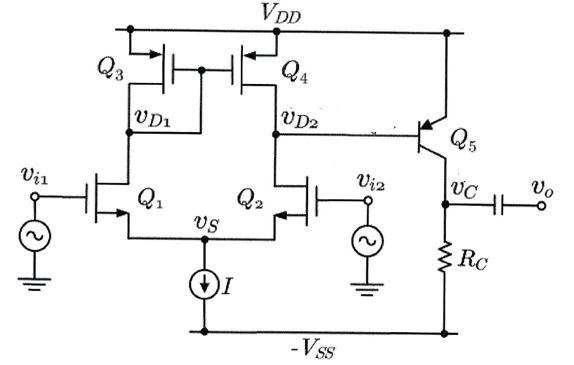


**Example#5**

For the circuit of Example#4, with the same parameters, calculate and all the other currents if .

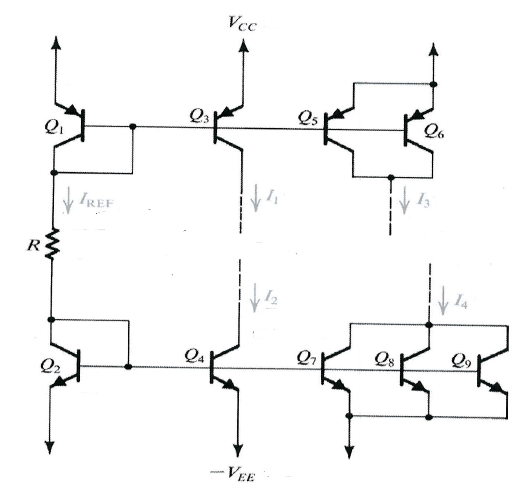
**Example #6**

In the following BiCMOS amplifier, the MOS devices are all of the same parameters. Also, assume that the current source is ideal and the Early effect is negligible for all transistors. Provide an expression for the differential-mode gain of the amplifier, i.e. in terms of of the MOS devices, of the BJT, and the resistance .



**Example#7**

Following figure shows a current-steering circuit in which the transistors are of the same parameters, and . Assuming that all transistors are in the active mode and is very large, calculate the labeled currents.



**Example#8**

Following figure shows a current-steering circuit in which all of the transistors are of the same parameters, except Q4 whose emitter-base junction area is four times that of the other transistors. Further, and . Assuming that all transistors are in the active mode and is very large, calculate the labeled currents.

