Tim Savas
Homework 07

1 Bipolar Diff amp

Solve for RC

Since we have $I_{quiescent}$ and the V_{supply}, we can solve for RC.

$V_{out\_quiescient}$ is the center point of the swing range. Given the +20V supply, 10V is the mid point between 0V and 20V

$$R = V/I$$
$$R = 10/.001$$
$$R_C = 10K$$

Solve for r_e

Solving for r_e is super easy and convenient with our “1mA” I_C value in this problem:

$$r_e = 25\ Ohm/I_C\ [in\ mA]$$
$$r_e = 25/1$$
$$r_e = 1$$

Solve for R_E

G_{diff} does not require R_{tail} and so we can use that equation to solve for RE. We know everything else in the equation: R_C, G_{diff}, and r_e.

$$G_{diff} = R_C/(2r_e + 2R_E)$$
$$50 = 10000/(50+2R_E)$$
$$50(50+2R_E) = 10000$$
$$2500+100R_E = 10000$$
$$100R_E = 7500$$
$$R_E = 75\ Ohm$$

Tim Savas
Homework 07

Attempted R_{tail}

We can try an R_{tail} to see if that will work. Let's give it a shot.

We are using a Darlington transistor pair, so there are two 0.6V drops, totaling -1.2V drops
So the voltage drop would be 18.8V.

$$I_{tail} = 2I_C = 2mA$$

$$2mA = 18.8/(R_{tail} + R_E)$$
$$.002 = 18.8/(R_{tail} + 75)$$
$$.002(Retail) + .15 = 18.8$$
$$.002(R_{tail}) = 18.65$$
$$R_{tail} = 9.3K$$

Why does this R_{tail} not work?

We can check to see if our circuit give us an adequate common-mode gain. That is, we need to meet the specification that differences have the gain of -0.1, or in other words, they get squished by 1/10. So let's check using the G_{CM} equation:

$$G_{CM} = -R_C/(r_e + R_E + 2R_{tail})$$
$$G_{CM} = 10000/(25 + 75 + 18600)$$
$$G_{CM} = -0.53$$

So no! This is not enough.

Constant current source:

Okay so instead of using an R_{tail}, we will spec a constant current source. This will always pull our desired current from the amplifier, as our constant current sources do well.
For designing it, first off, what is the desired current again? It is simply 2x I_C, so 2mA.

Tim Savas
Homework 07

Next we will setup a transistor such that it has an I_E, and therefore an I_C of 2mA. The I_C will connect from the diff amp tail. We know we have a -20V power supply to connect to. Therefore we want to spec R_E.

Let's make it easy and say we want to drop 2V across some R to produce 2mA I_E. R_E then equals 1K.

This gives us -18V at the top of the emitter before R_E.

That means that V_B has to be -17.4V

So the last step is to create a voltage divider that takes -20V in and outputs -17.4V into our base. That's just a Vin to Vout problem with some Rs.

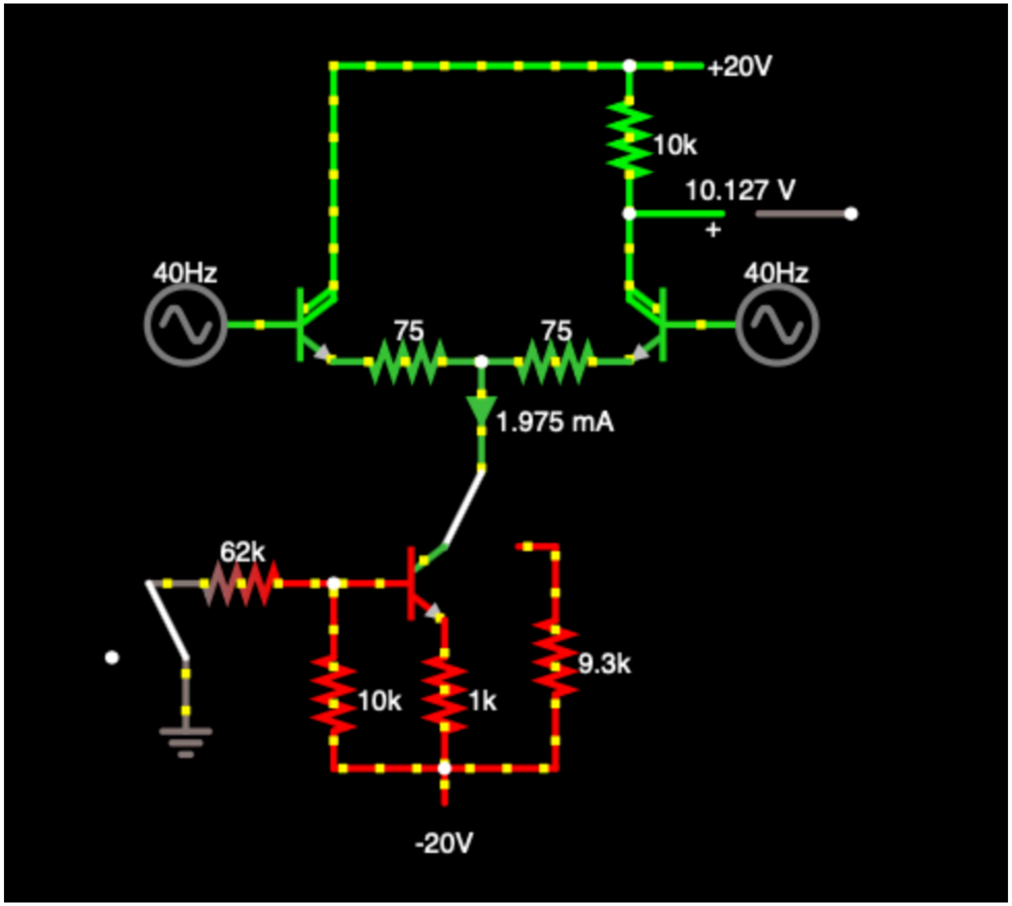
Vout = Vin(R2/R2+R1)
-17.4 = -20(R2/R2+R1)

Values that work are:
R1 = 10K
R2 = 62K

Here is my circuit on Falstad: https://tinyurl.com/y3ysocco

I have installed the 9.3K R_{tail} and some switches, along with an ammeter at the tail in order to observe the current. Notice that it is not a constant enough current, and when you switch it over to the constant current source, the current stops wiggling!

Tim Savas
Homework 07



Tim Savas
Homework 07

1.2 Input current

Wow good question. So I think this is a simple IC vs. IB current question with a twist. The twist is that we are using a darlington pair, so actually are dealing with two betas. So the solution for this should be:

$$I_C = \beta^2 \times I_B$$

$$I_B = I_C/\beta^2$$

$$I_B = .1/10000$$

$$I_{B\_quiscent} = 0.1nA$$

I've added an ammeter to the base of the diff amp in my circuit simulator on Falstad and it looks like this is right!

Falstad link: https://tinyurl.com/yxen2ntd

Tim Savas
Homework 07

2 Level Shifter

Overview

My solution is here on Falstad: https://tinyurl.com/y6tmxugy

This problem can be broken down into a few steps, and those steps can be achieved by different op-amp stages. It's kind of like making a car wash that we will put the signal through. First we wet the signal down, soap, rinse, wax, and finally dry. In short, the stages are: 1) optimize the Rin, 2) amplify it by 4x, 3) adjust the offset and any incurred inversion.

1) Rin

We don't know what kind of Rout of the source we're working with, as the problem describes. We can simply add a follower at the start of the circuit to take care of this. In my simulation, this stage's output, the source output, is labeled red.

2) Amplification

We're going from 0-5V to -10-10V. Leaving aside the offset, this is a gain of 4x. We can use an inverting amplifier for this. We determine the Rs according to the easy equation: G = -R2/R1. So we have 4K and 1K respectively. Note that this unintentionally flips the wave, but we can fix that. In my simulation, this stage's output is labeled green.

3) DC Offset

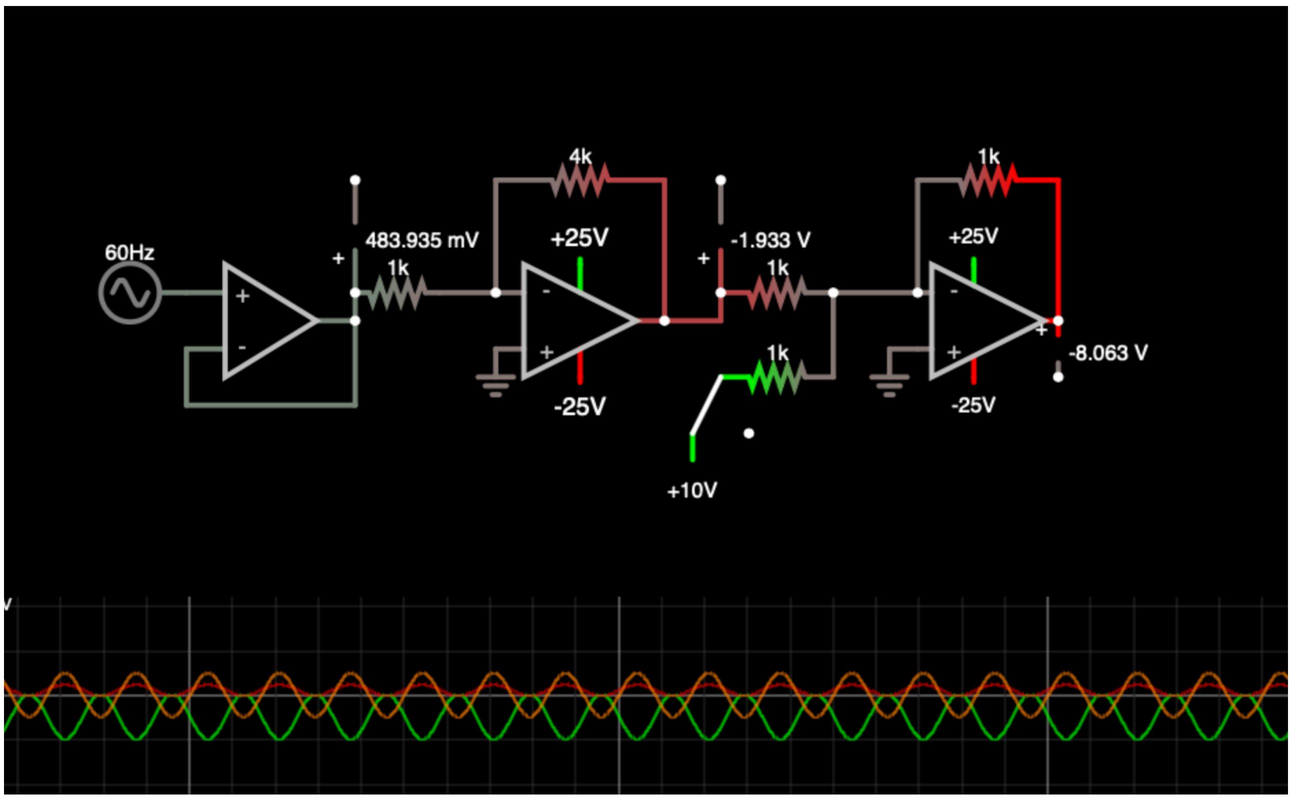
We're not left with a signal that is correctly 20V in amplitude, but its offset doesn't match what we want yet. As of the last stage's output, the range is -20V to 0V. This means we need a DC offset of 10V. We can use a summing circuit for this. Conveniently, we can use two equal Rs in the summing circuit and have it act as a second inverting-amp, which will flip the wave back into the correct phase.

Tim Savas
Homework 07

In this table I have done my equations for the summing circuit. The trick is to convert the Vs we're working with into currents according to resistor values we plug in. It is the currents that cleanly sum, not the voltages.

So we end up with a summing circuit that injects an extra 10mA, from a 10V source across a 1K R. In my simulation, this final stage's output is labeled orange.

Ra	Rb	Va_in	Vb_in	Ia	Ib	Isum	Rc	Vout
1000	1000	-20	10	-0.02	0.01	-0.01	1000	-10



3 AM Modulator

Solution on Falstad: https://tinyurl.com/y3gbssuk

Solve for RC

Since we have $I_{quiescent}$ and the V_{supply}, we can solve for RC. Note that 1mA at each transistor sums to 2mA at the collector. $V_{out\_quiescient}$ is the center point of the swing range. Given the +15V supply, 7.5V is the mid point between 0V and 15V:

$$R = V/I$$
$$R = 15/.002$$
$$R_C = 7.5K$$

Placement of Carrier

As in the diagram, this gets put into the base of one of the transistors. The other transistor gets grounded.

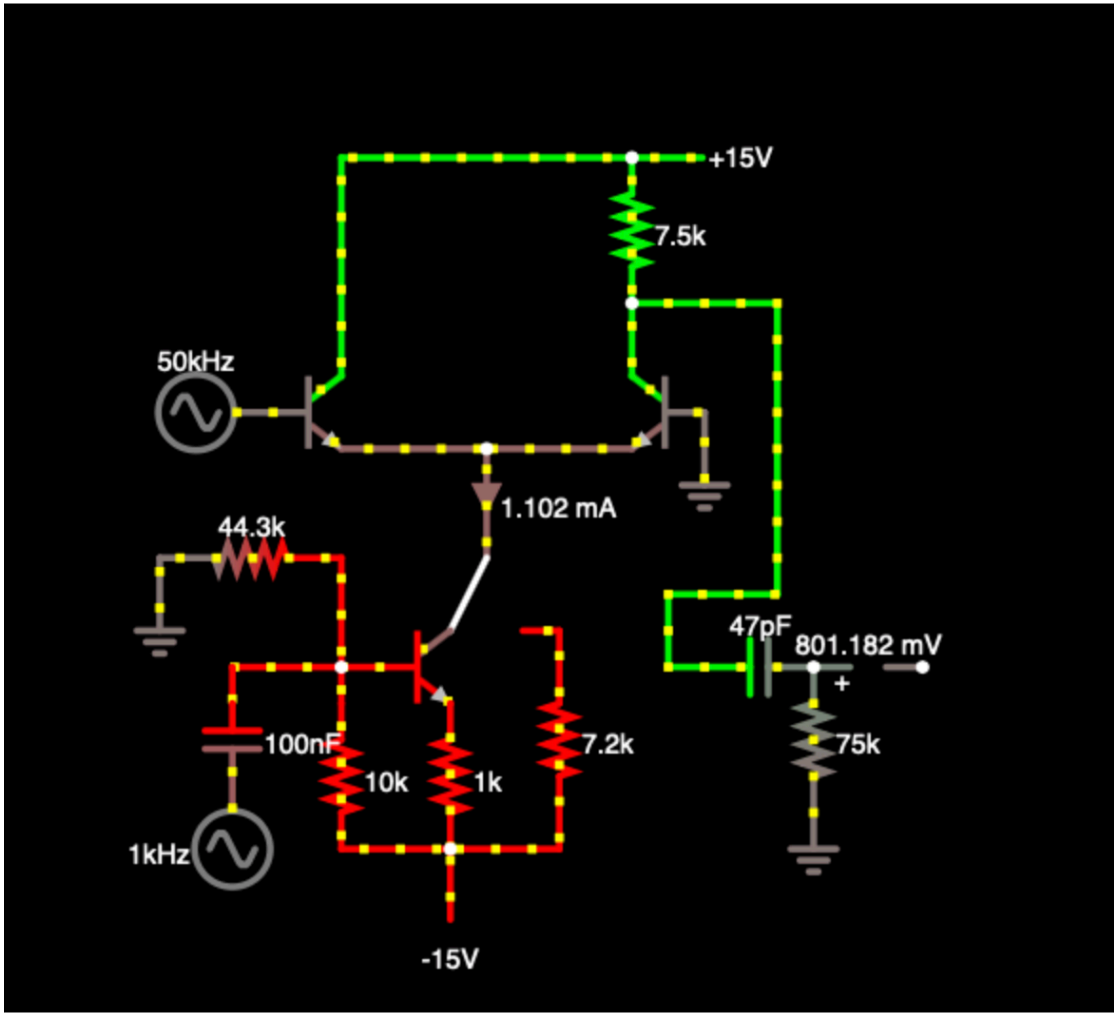
Solve for R_E

This is a high-gain diff amp so we're not using REs for this circuit.

Remainder:

The remainder of the problem is to solve for the constant current source that needs to be at the diff amp tail. For this we use a 1K R. For proper biasing we use a R1 and R2 of 10K and 43K. Last step is to get rid of the low frequency noise on the output with a high-pass filter.

Tim Savas
Homework 07



Tim Savas
Homework 07

4 Bad Circuits?

1) Bad one. This needs a R between the transistor base and V_{souce} for proper biasing.
2) Bad one. This probably needs a R that biases the transistor to ground. Interesting discussion during office hours on this one. Agree that it's odd to see a current source at the transistor base, since we're usually not pulling much current there. This is my recommendation in any case.
3) This works.
4) Bad one. This needs Rs on the respective V_A and V_B inputs. Looks like current will flow, but the circuit won't be pulling current from the respective inputs in any meaningful or proportional way, as to make this a useful summer.
5) This works.
6) Bad one. This is actually an averaging circuit, as described on page 256. The fix is to apply a gain of 2. That's easy to do by also conforming this op-amp to be a non-inverting amplifier with some resistors. Here it is on Falstad: https://tinyurl.com/y4r6q63x
7) Bad one. It is close. It needs a R between the negative input and the output of the third stage op-amp. As it stands I believe this may cause some infinite or run-out condition. I haven't tested that but it's a guess from my nascent op-amp intuition!
8) Bad one. For this to be a current source, the load should be at the transistor collector. Either that or switch this from a NPN to a PNP transistor, keep load where it is, and the emitter and collector get properly mirrored. See page 257 Figure 6N.16.

5 I to V

Interesting problem. We will build a current-to-voltage converter, as referenced on page 258.

For this circuit, $V_{out} = -I_{in}R$

We're sinking current—it's coming out, not into the circuit—so we can remove the negative by saying $V_{out} = I_{sink}R$[1]

The first thing to do is the conversions. This will inform the ratio of I_{sink} to V_{out}. From there we can figure out R. The last step is to resolve the offset: notice that 0 current is not 0 degrees.

Conversions & R

Here is a table where I figured out the conversions and then the requisite R value. I produced a ΔV and ΔI which allows us to solve for R. I also picked another arbitrary value set just to verify that the deltas and resulting R all stay proportional.

Temp, K	Temp, °C	I_{sink} Temp (K) x $1/10^{-6}$	V_{out} Temp (C) x .1	ΔV $V_2 - V_1$	ΔI $I_2 - I_1$	R ΔV/ΔR
273.15	0	0.00027315	0	0.1	0.000001	100000
274.15	1	0.00027415	0.1			
383.15	110	0.00038315	11	-10.5	-0.000105	100000
278.15	5	0.00027815	0.5			

R = 100K

[1] Hold on a second. I might have this wrong. I still get a negative sign on my Vout on my simulation. I'll have to go back to this!

Tim Savas
Homework 07

Resolving the offset

The problem is not done. There is still an offset to solve for. As it stands, if we sank 0 current—if the sensor read 273.15K, 0º C—the Vout would not be 0V. It would read 15V, which isn't right.

We can resolve this by leveraging op-amp "Golden Rule 1: The output tries to do whatever is necessary to make the voltage difference between the two inputs zero."

We can tie the +input of the op-amp to a -27.315V power supply. This will require the other op-amp input to pull down this same voltage and therefore calibrate the V_{out}.

Here is my circuit working on Falstad: https://tinyurl.com/y5dx9txg