A guide

to my own discrete operational amplifier with bipolar transistors

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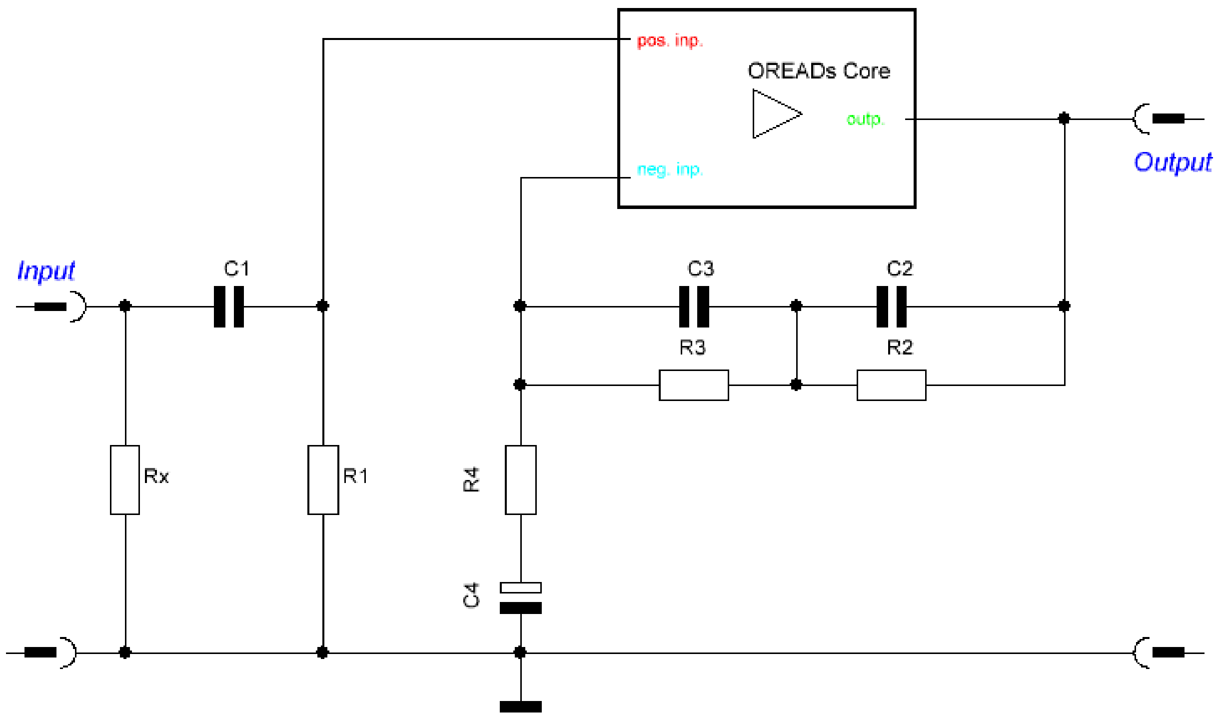
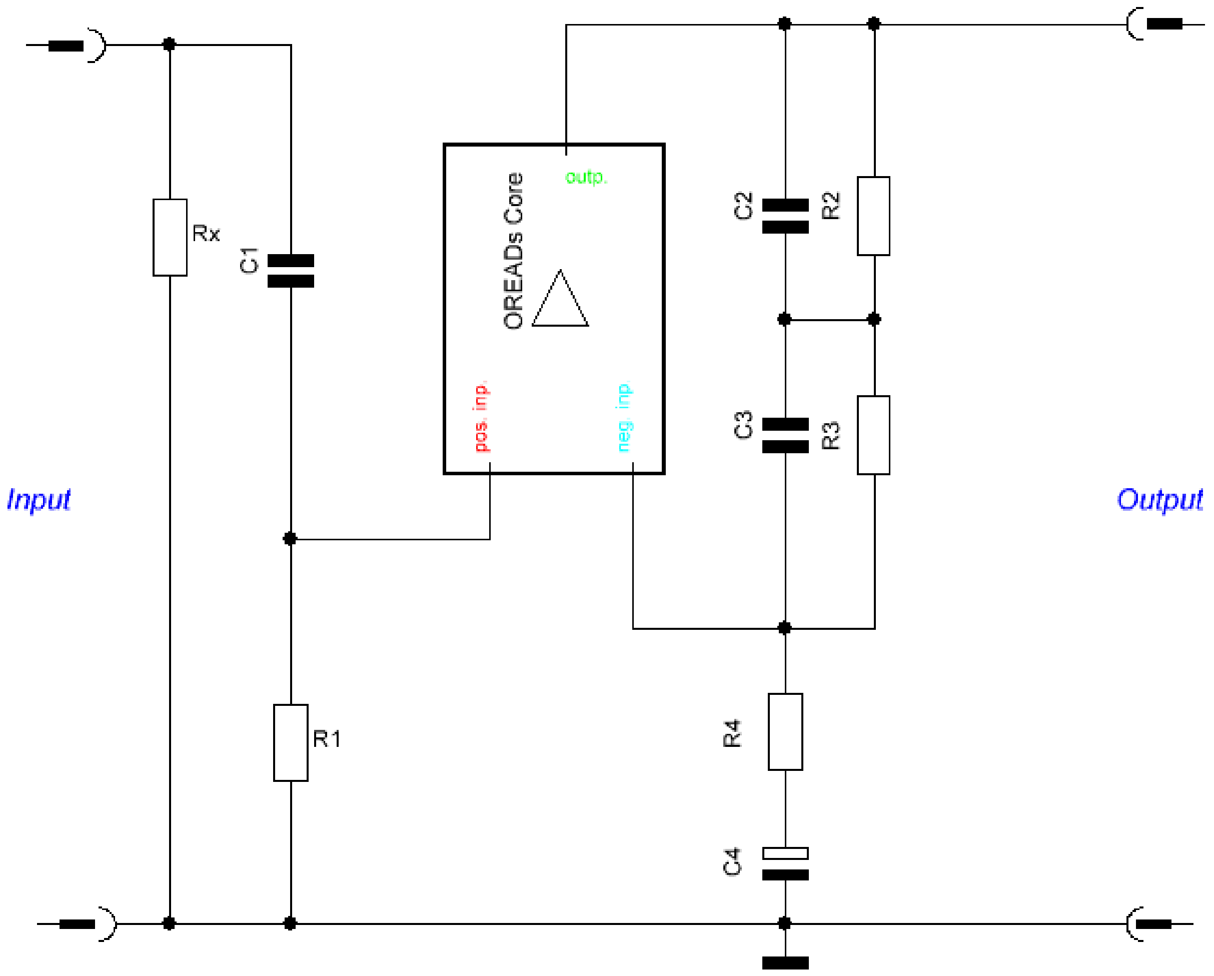


At first glance we recognize two inputs and a common output, the "negative input" is fed by the "positive output" of the actual amplifier (the term positive refers to what happens at the other input, which we use for level control - as the MM pickup input), this is generally called feedback as we know.

The next picture is only drawn slightly differently, shows the situation - perhaps we should now recognize the two complex voltage divider easier, one on the left and another one on the right.

The introduction has already taken us very far and we can jump straight to the eighth paragraph, ignoring the following repetition.



We could go on and on, but it's better not to digress at this point, just briefly:

The core (an ideal operational amplifier) automatically ensures via its output that its input voltage, namely the difference UR1 - U|Z4(jω)| tends towards zero. If we imagine the reactance of C4 as a short circuit, which is legitimate, then the expression is simplified to UR1 minus UR4 equals zero.

This automatic process is also known as the "principle of the vanishing input variable".

The input variable is therefore a differential voltage, but the actual process is only possible through a control loop, our negative feedback. What we need is an amplifier with two inputs.

A first idea; without hesitation, we choose two identical transistors and identical circuits, the so-called emitter circuit.

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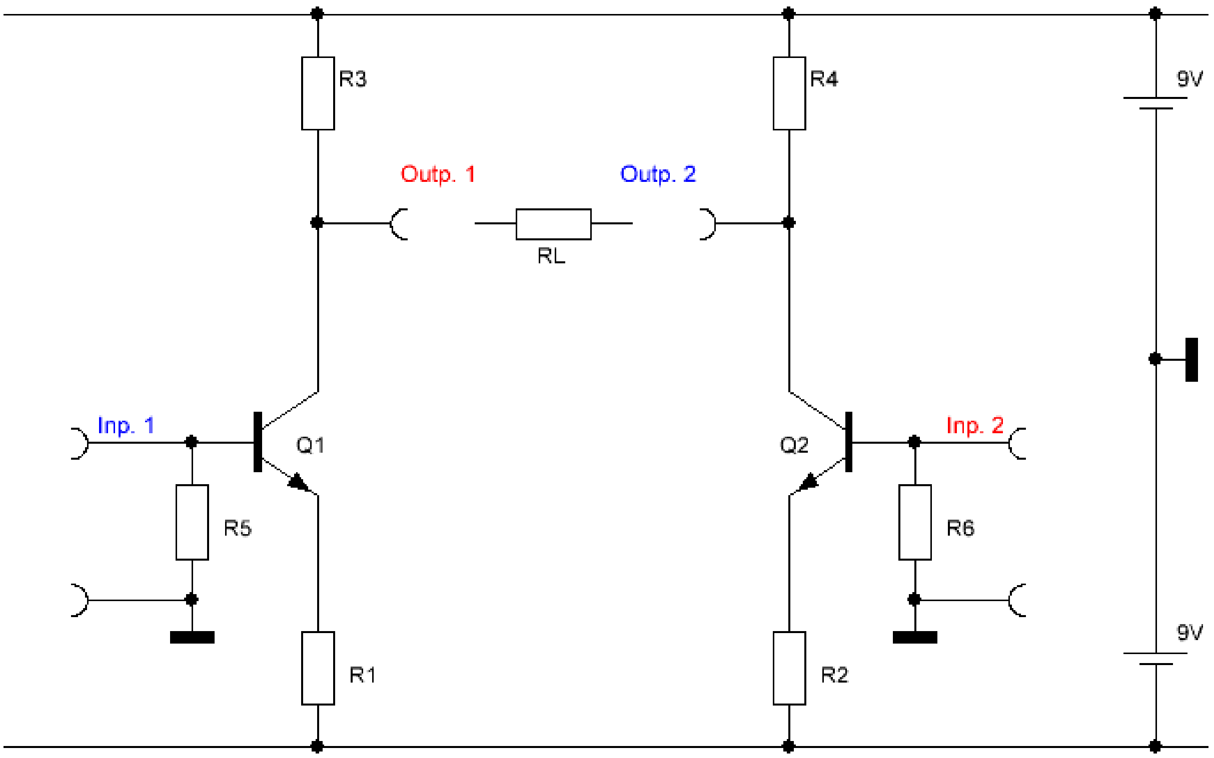

The base potential is automatically greater than the emitter potential (the voltage of the respective electrode in relation to the reference, the zero voltage at the point we call ground or earth), i.e. Q1 & Q2 are in a conductive state and currents are flowing.

From now on, everything is an easy task, just as to play with Lego bricks. Because we only need to follow the static path without exception, dynamic consideration is not necessary at this point.

$R1 = (9V - U_{BE}) / I_{R1}$

We can set U_{BE}=0.7V and I=0.5mA. 9V is given by (us) the selected supply voltage as well as 0.7V for the diffusion-voltage at the silicon PN junction - we are again only determining reference points for later optimization.

R1=R2 equal to 16.6kΩ.

Anticipated the fact that U_{R1} is a so-called potential difference, like all voltage (drop) cases or voltages.

$R3 = (9V - UC_{Q1}) / I$

Now it gets tricky, because it is not so easy to determine the collector potential of Q1 or Q2, but it will later be greater than 9V/2. If the guide had already ended at this point, U_{R3} would now be 4.5V and R3=9kΩ.

This so-called operating point (on the working line in the first quadrant of a four-quadrant characteristic field to describe an LF transistor - linear) is also called single-ended class A.

The value of the current, which we have largely chosen freely, is considered to be impressed, i.e. it itself also flows through the working resistor R3. To do this, only the operating voltage rails need to be constant.

$I = (I_{R1} = I_{R3})$

R3 = R4

Thats all while we (may temporarily) consider R5=R6 as high-impedance 1MΩ resistors.

The result of this first intuitive step is a bridge, a bridge amplifier or balanced amplifier; a balanced input and a balanced output. Both branches swap the polarity of their respective inputs, but they do not amplify - R1 and R2 will take care of that, they lead to current-voltage-feedback-loop and stabilize the operating point.

AC voltage amplification here largely depends on the ratio R3 to R1. And that is currently less then one.

For this (amplification) we need a real differential amplifier, which is now simply realized by connecting the two emitters with each other - we let them work on a common potential.

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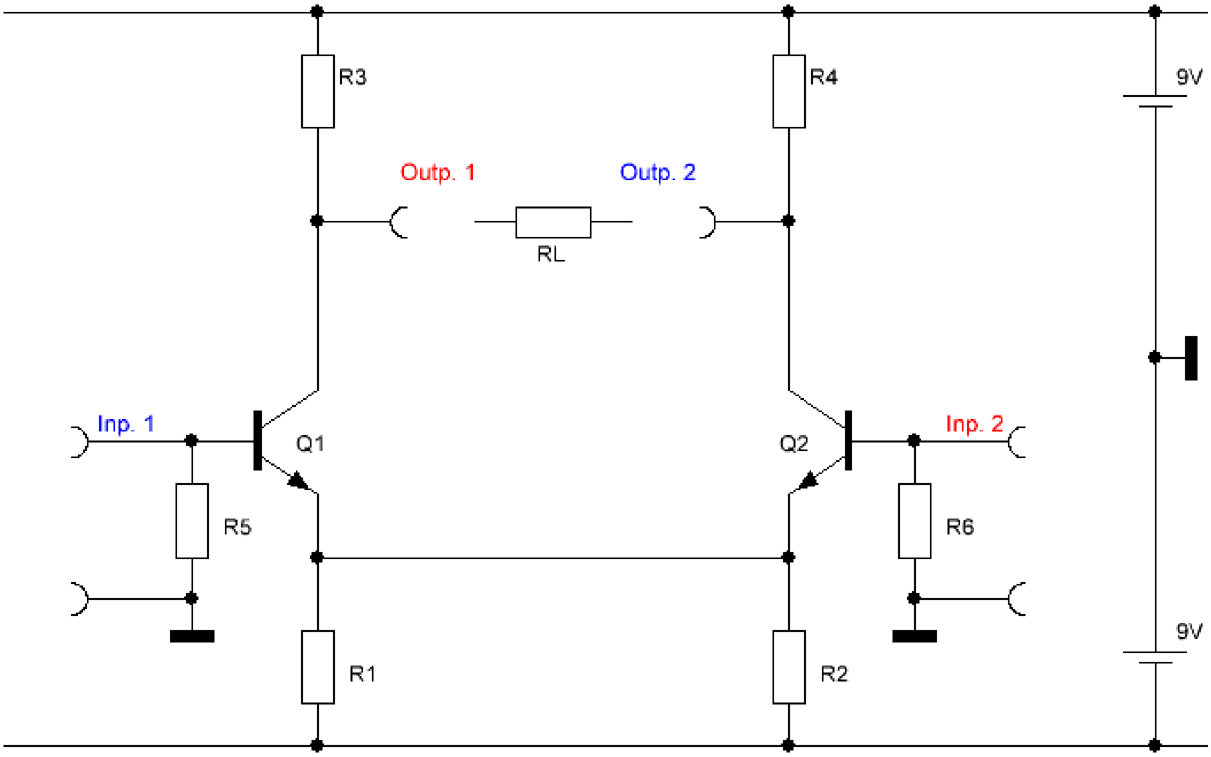

For Q2 is Q1 now working as a impedance converter, an emitter follower that wants to communicate something to its emitter electrode. For Q1 is Q2 a further processing stage, an amplifier in a so-called base-circuit.

The crazy thing is : this also applies in reverse, crosswise so to speak. Finally, the construct (the bridge) even amplifies DC voltages.

From a dynamic perspective we could already calculate the AC amplification factor, but to do this we would not only have to know and be able to describe the transistor exactly, but also know what the adjective dynamic or differential (i.e. also infinitely small) in this context means.

We just summarize the resulting parallel circuit R1||R2 = R7.

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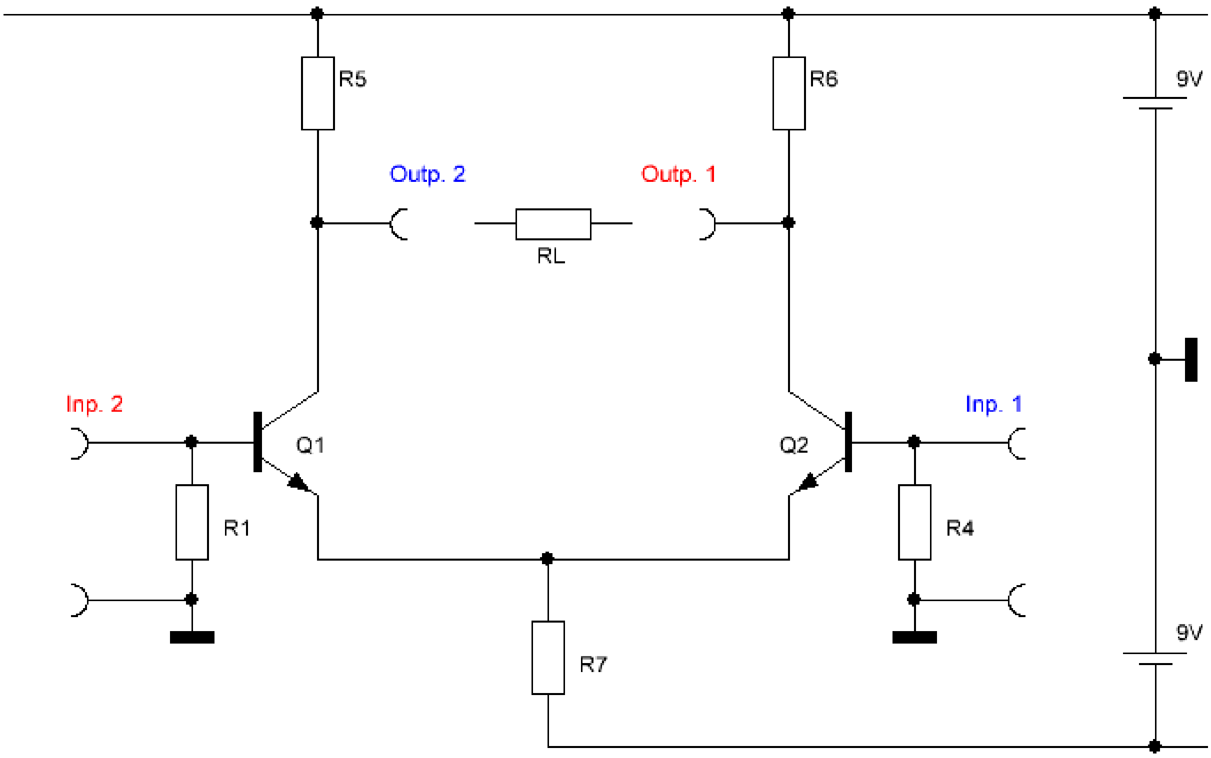

And finally obtain a usable first stage of the entire core.

R7 = R1 / 2
= 8.3kΩ

The current I, has of course doubled and is now 1mA – because the Voltage (drop) stays the same.

If one of the two branches, its transistor blocking, is no longer in the race, then we simply calculate a new reference point for R5 and R6.

R5 = 4.5V / 1mA
= 4.5kΩ

The value of R1 (and R4) is currently of secondary importance. Set to 1MΩ is fine.

We leads us now to the selection of values from the known levels of the E-series. For example 1M, 8k2 and 4k3.

Now we can theoretically also calculate the amplification factor of this stage; for this we need to select a suitable BJT - at this point, it would be beyond the scope of this guide to go any deeper.

We can't have achieved the complete solution yet, even if we already have a usable input stage at this point.

The resulting amplification factor of a single, simple differential amplifier is unfortunately not sufficient for our application. A second stage must follow and this should also be implemented as a differential amplifier. This brings us quickly and safely to the desired goal.

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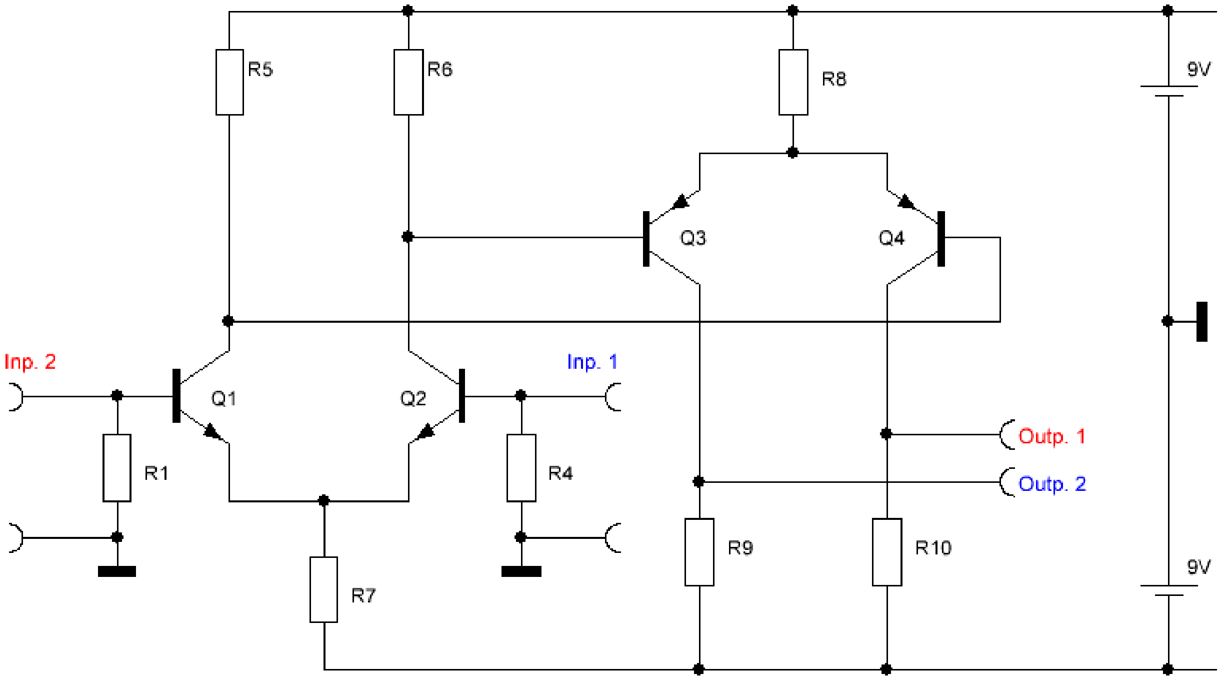

R8 is now calculated in one go and thus determined, but all numerical values are only indicative, i.e. provisional.

U_{R8} = (R3*0.5mA) - 0.7V = 1.45V

To calculate R8, the corresponding current is still missing. In short: Doubling, 2 * I of the first stage, leads to 2mA.

R8 = 1,45V / 2mA = 725Ω
We approximate this value according to the E24 series and select the value 750Ω for R8.

Correctly balanced, two equal currents with the value 1mA now flow in the left branch R9 and in the right branch R10.

R9 and R10 could now be calculated according to the now familiar pattern,
for example: (9V - 6V) / 1mA = 3kΩ.

But the reasons, the “why” is missing - completely different currents and potentials could have been specified. However, the now dimensioned two-stage differential amplifier already works perfectly. He is not yet complete and his output is symmetrical.

In the following part, we cleverly link the outputs and form a common but asymmetrical output.

Any knowledge we may have about electronics, current sources and sinks should be thrown overboard on this journey – feel as free and innocent as (to be) a beginner.