Equalizing the Currents in Wilson Current Mirror[1]

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Abstract: *This paper reveals the secret behind the unique feature of the popular Wilson current mirror circuit to equalize the input and output currents. The general idea is revealed step-by-step by applying a heuristic approach. First, the disadvantages of the basic current mirror circuit are shown. Then, three possible solutions of the equalizing problem are considered. Finally, the advantages of the last solution are revealed.*
Keywords: *Wilson current mirror, BJT current mirror, current source.*

1. INTRODUCTION.

Current mirrors are basic building blocks used in electronic circuit designs of today. A great number of integrated circuits are based on current mirrors (even there are whole op-amps made only by current mirrors). There is variety of current mirror circuits; Wilson current mirror is one of the most popular of them. Although this clever circuit consists only of three transistors (Fig. 1) it is too difficult to understand what the basic idea behind it is and how it operates because it is explained usually by formal means that do not reveal the root of the matter.

The simple BJT current mirror has two principal disadvantages: a finite output resistance due to Early effect and a significant difference between the input and the output current. In [1] it is shown how the problem of eliminating the Early effect is solved smartly in Wilson current mirror. Here, we will show how the other problem -- equalizing the input and output currents – is solved in Wilson current mirror.

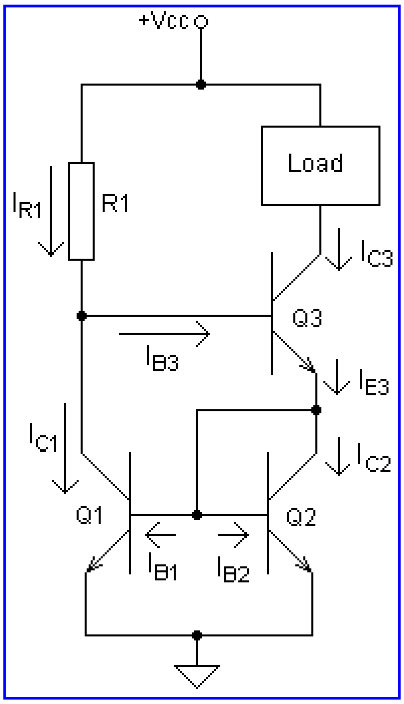

Fig. 1

Because the purpose of this paper is rather to reveal the basic idea behind this exotic circuit solution than to calculate its parameters a qualitative heuristic approach is used.

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[1] *I dedicate all my insights about the legendary circuit that I have exposed in this paper to my love who inspires me to continue revealing the secrets of electronic circuits. You may also visit the web version of this paper presented in Circuit idea wikibook at the web address below:*

http://en.wikibooks.org/wiki/Circuit_Idea/How_the_Wilson_current_mirror_equalizes_the_currents

2. THE CURRENT DIFFERENCE IN THE BJT SIMPLE CURRENT MIRROR

In order to grasp the ideas behind circuits, we may visualize electrical quantities *voltage* and *current* by voltage bars and current loops. In the case of current mirrors, it is extremely interesting to show where currents flow and to visualize their magnitudes.

Let's begin with presenting the simple BJT current mirror in an attractive way. You can see on Fig. 2a where currents flow and particularly how the transistors "suck" two base currents. Note how the currents are represented by closed loops (every current finishes where it has started). The lines on Fig. 2b are actually sections of the current loops from the left one. The transistors are shown with extremely low ß (here ß = 4), in order to present the base currents by thick enough lines.

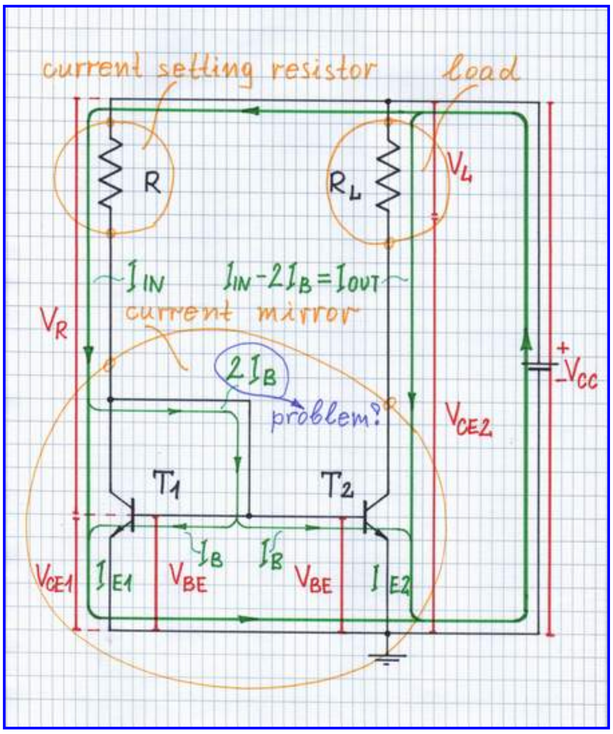

Fig. 2a

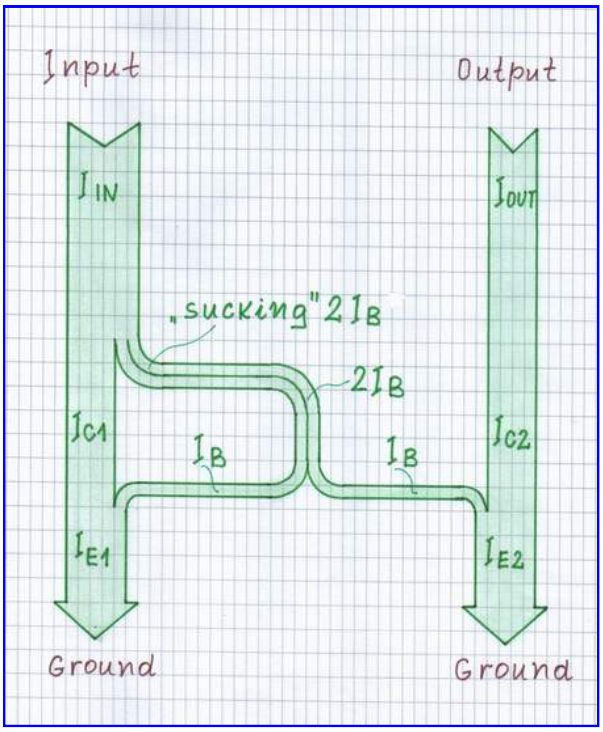

Fig. 2b

3. EQUALIZING THE CURRENTS BY "PUSHING" 2IB TO IIN...

How do we solve the problem of the two I_B in the simple BJT current mirror? Let's begin thinking relying on our human common sense... We know from daily routine the great idea of *compensation*: if there are some losses of "something", we compensate them by adding the same quantity of this "thing". So, let's put in practice this powerful idea!

Since the transistors "suck" two I_B, the first idea that might dawn on us is, of course, to add the same two I_B (Fig. 3b). Then $I_{OUT} = I_{IN} - 2I_B + 2I_B = I_{IN}$. For this purpose, we have to connect an injecting current source $2I_B$ to the T_1's collector – Fig. 3a (more precisely speaking, this is rather a *current-stable resistor* than a current source). Only, this has to be not an ordinary constant current source but a "following" current source that copies the current $2I_B$. But it turns out that we need another current mirror?!?

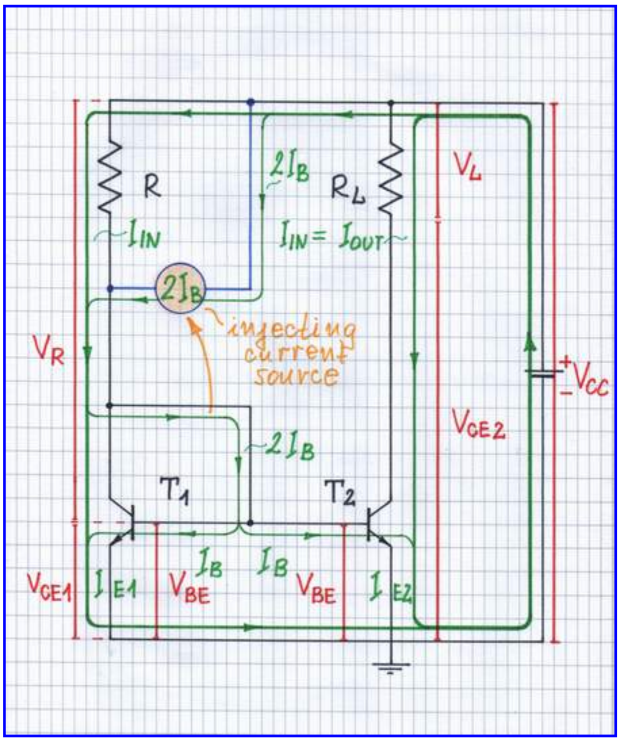

Fig. 3a

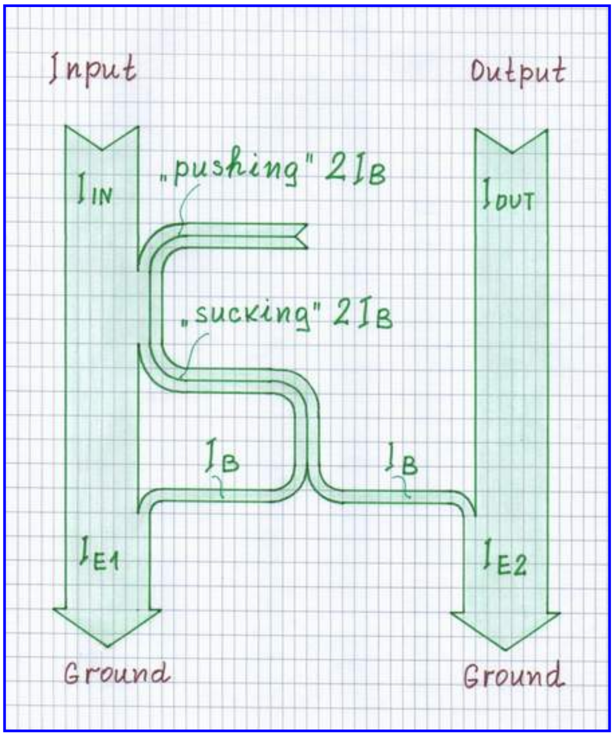

Fig. 3b

4. ...BY "SUCKING" 2IB FROM IOUT...

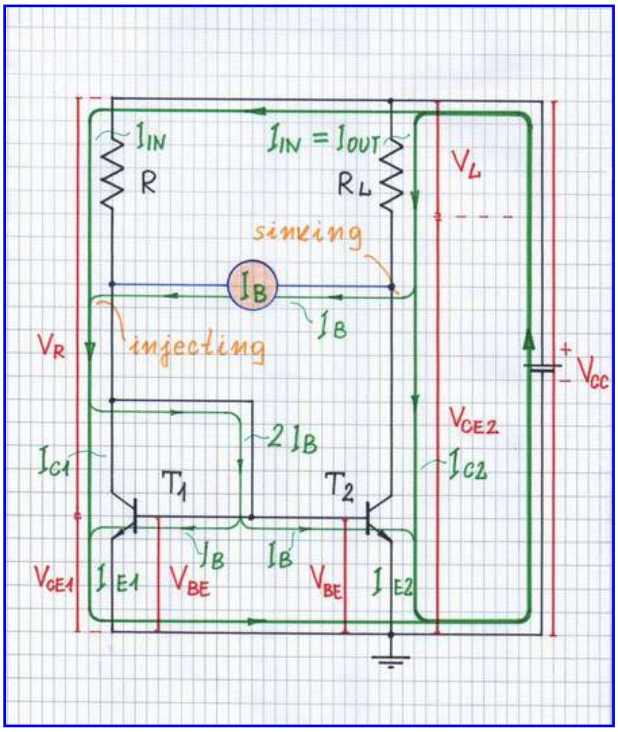

Fig. 4a

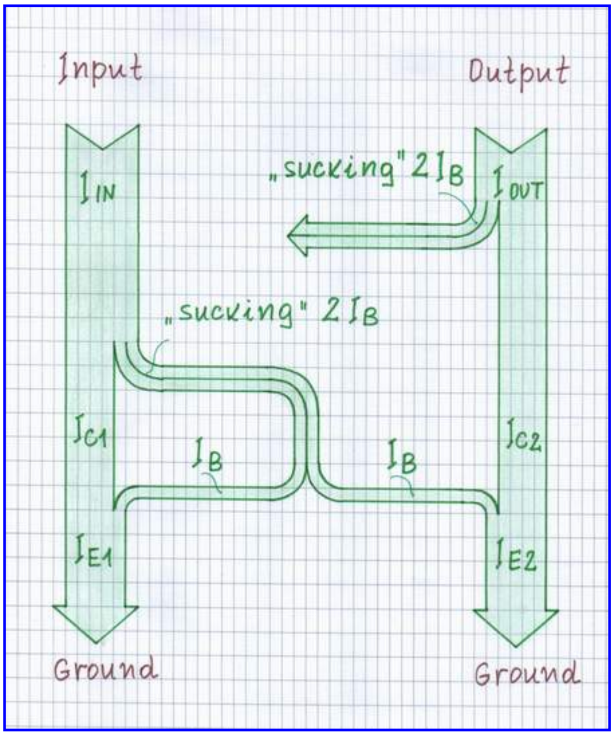

Fig. 4b

Above, we have added the two compensating base currents by injecting them into the input current (the "original" quantity). But with the same success we might add them to the output current (the "copy") by "sucking" $2I_B$ from it (Fig. 4b). Now $I_{IN} = I_{OUT} - 2I_B + 2I_B = I_{OUT}$. In this case, we have to connect a sinking current source $2I_B$ to the T_2's collector (Fig. 4a). As before, this has to be not an ordinary constant current source but a "following" current source that copies the current $2I_B$.

5. ...BY "SUCKING" IB FROM IOUT AND "PUSHING" IB TO IIN...

We have almost reached the great Wilson's current equalizing idea... Well, let's continue thinking. It is inconvenient to create $2I_B$; it is easier to produce (source or sink) only I_B…

Eureka! We might connect a current source between the two collectors that sinks a current I_B from I_{OUT} and injects the same current I_B into I_{IN} (Fig. 5a)! In this way, we add one base current to the input current and another base current to the output current (Fig. 5b). As a result, the two currents become equal: $I_{IN} + I_B = I_{OUT} + I_B$, $I_{IN} = I_{OUT}$.
Here is the great Wilson's idea! In order to equalize the two currents, ***he has "moved" one base current from the one to the other leg***!

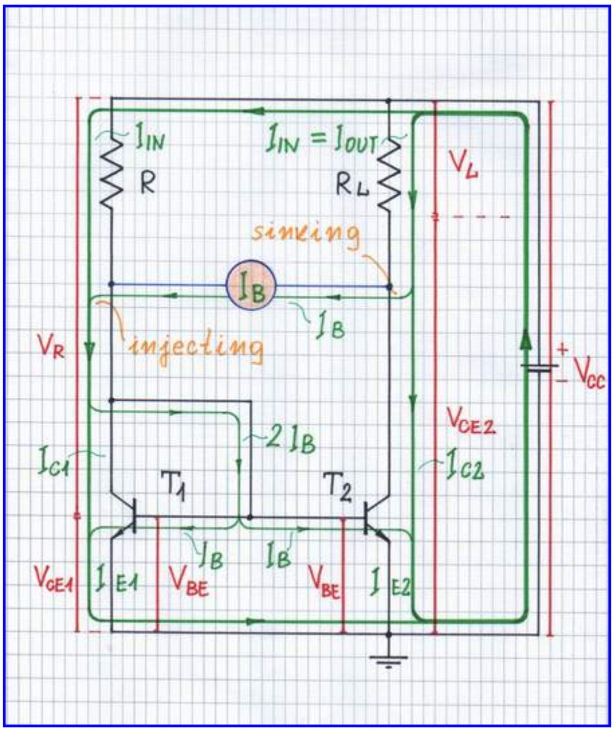

Fig. 5a

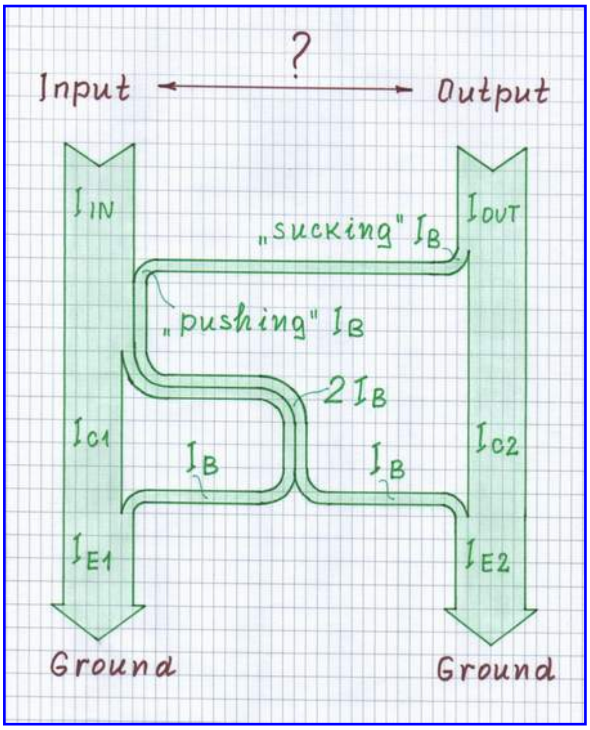

Fig. 5b

6. REALIZING THE WILSON'S CURRENT EQUALIZING IDEA

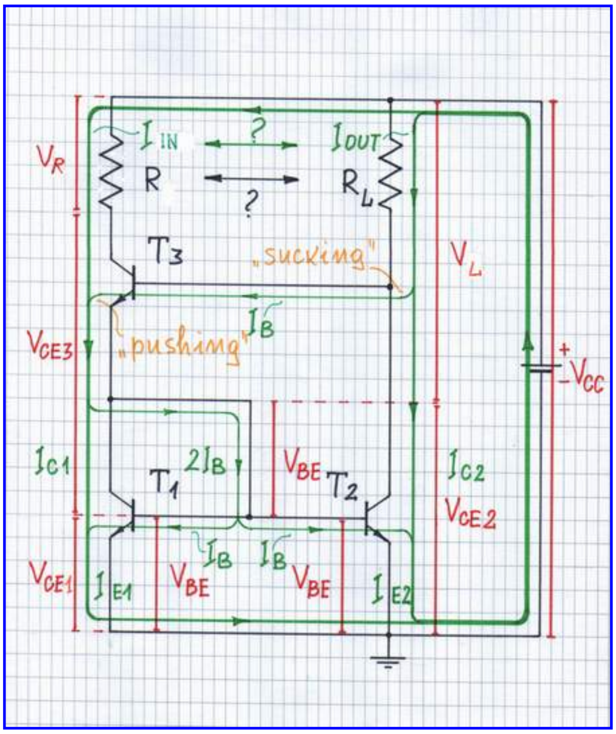

Fig. 6a

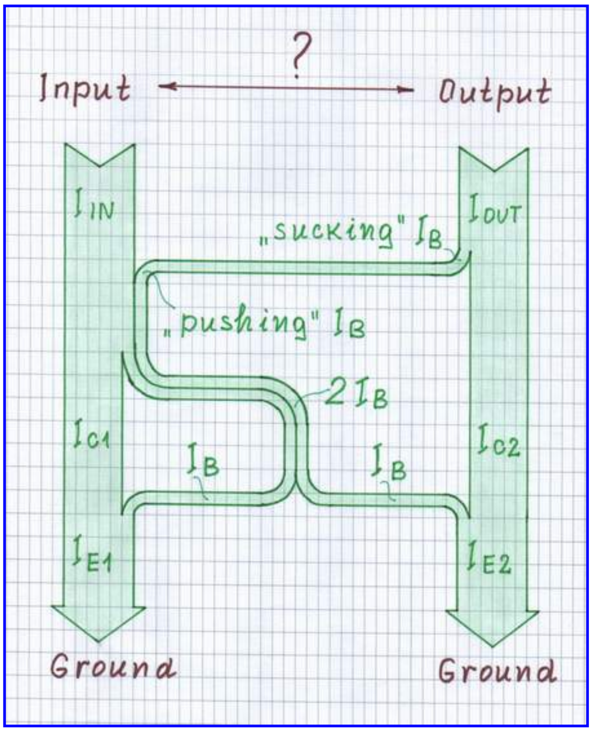

Fig. 6b

Once we revealed the brilliant Wilson's idea we have only to implement it... What is this mysterious element that can consume I_B from one part of the circuit and can add it to the other part? Of course, there is nothing more natural for a bipolar transistor to do that "donkey work"! It "sucks" I_B from the point where its base is connected and adds it to the emitter current. Then let's connect a transistor T_3 in the left leg of our circuit (Fig. 6a). Wonderful, now it sinks the current I_B from I_{OUT} and injects the same current I_B into I_{IN} (Fig. 6b)! So, we have managed to reveal the role of the mysterious transistor T_3!
In the circuit of Wilson current mirror, the transistor T_3 "moves" one base current from the right to the left leg.

7. CONCLUSIONS.

In this paper, we have showed how the heuristic approach may be used to reveal the secrets of legendary Wilson current mirror. For this purpose, we have presented the circuit by reinventing it, showing the circuit evolution and visualizing the circuit operation by means of voltage bars and current loops.

We may use the same heuristic approach in analog circuitry and education for processing other complex and abstract electronic circuits (e.g., cascode and negative resistance circuits).

8. REFERENCES.

[1] Mechkov C., Eliminating the Early effect in Wilson current mirror, The 4th Int. Conference Computer science'2008.
[2] Circuit idea: How the Wilson current mirror equalizes the input and output currents
(http://en.wikibooks.org/wiki/Circuit_Idea/How_the_Wilson_current_mirror_equalizes_the_currents)