ELECTRONOTES

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ENWN-28

FUN WITH "World's Simplest Circuit"

INTRODUCTION:

At some point I found myself on the mailing list for the website "Planet Analog" and it is a site most readers here will find well worth looking at. In a recent posting the inclusion of the name Bob Pease caught my attention. Bob (sadly missed now) would be at the top or very near the top of the list of best analog designers. Here is the item that caught my eye.

http://www.planetanalog.com/author.asp?section_id=3330&doc_id=564080&_mc=NL_PA_EDT_PA_20151028&cid=NL_PA_EDT_PA_20151028&elq=1ec4b561d4844ba9a0dbc78607566156

Don't read it until you have at least tried to solve the puzzle here. Yes, I will give the answer below too. I could not figure it out myself.

The circuit consists of just a simple silicon NPN BJT (like 2N3904) and a resistor along with a +12 volt supply and is measured with a high impedance voltmeter. The resistor is something like 1k, and the transistor emitter/base junction being reversed biased looks like a Zener diode (roughly the 7.9 volts shown independent of R). Familiar.

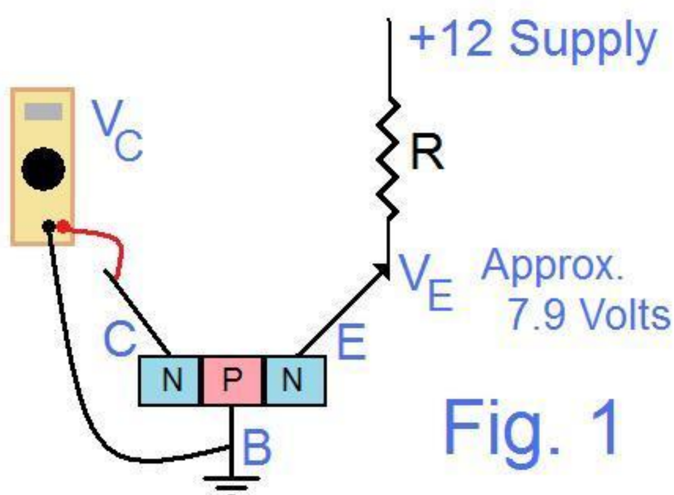


Fig. 1

But when we measure the voltage V_c we get values of -0.21 to -0.36. The puzzle is first "Why is there <u>any</u> voltage at V_c?" and second, "How could it possibly be negative!" Think about it before "turning the page."

Here I am going to explain what is apparently going on, and in writing this, it may be the case that it sounds like I figured it out myself. I did not – I cheated and looked for the answer as probably many reading here are currently doing. I didn't need much of a hint, and likely neither will you: Zener diodes emit LIGHT. You don't notice it because the diode (or reversed biased transistor junction) is sealed. You of course know that diodes can emit light – the familiar LED. Apparently a LED is a Zener diode. Who knew?

So now it is clear that the EB junction is producing photons and some of them find their way to the CB junction where they photovoltaically generates a small voltage, which is monitored by the high-impedance multimeter.

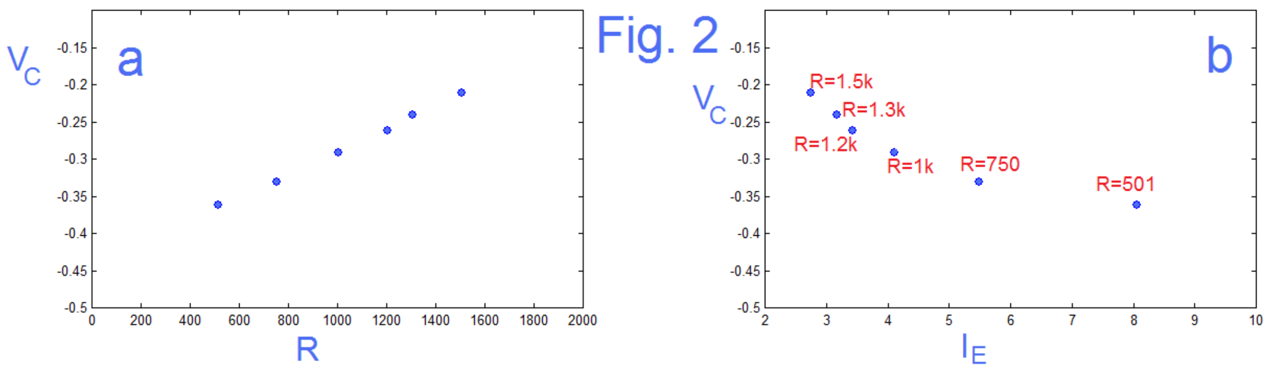
[Certainly everyone today is aware of the generation of voltage (at times!) from light (solar energy). In the old days (1960's) you could purchase "sun batteries" for about $3.50 each and an array of these could power a small radio. These could also be used to detect light, perhaps to turn off outside lighting, or as intrusion indicators as beams of light were interrupted. Endless fun. At the same time, transistors were as much as $3.50 too. But by some miracle Lafayette Radio (a supplier of hobby electronic, since defunct) offered a transistor for something like 59 cents (the SP-146). A feast. These were metal cased, so you could file the cap free and see the actual transistor – if you wanted to. I must have read it somewhere, but I became aware that if you shined light on the junction, it would act as a weak but usable "sun battery" to the extent of light detection – not enough for power of course. I made a demo circuit for an automatic "high-beam" switch that responded to a flashlight beam. So I knew that light hitting a transistor junction could have very modest voltage consequences. But mostly transistors were in metal cans or in black plastic.]

So reading the explanation at "Planet Analog" I believed the phenomenon was real, and was left to wonder why it was not well known. After all, a "circuit" powered from a positive supply putting out a negative voltage requires considerable tricks:

http://electronotes.netfirms.com/ENWN7.pdf

The explanation made sense, and Bob Pease enjoyed an impeccable reputation. Still, would we not like to test it? Seeing is believing. And what determined the output voltage. Clearly it was a function of EB current, at least to the extent that when there was no current, there was no voltage at the collector (one supposes). How hard is it to breadboard a circuit of two components? Of course, it's easy – except as one might forget the base diagrams of a transistor and that sort of thing. The table below shows the results of a test with a +12.0 volt supply, and values of R of 510 ohms, 750 ohms, 1k, 1.2k, 1.3k, and 1.5k. The emitter current is basically (12 - 7.9)/R. As we would expect, larger values of V_c are associated with larger currents. The experiment had the limited goals of assuring us that it really does produce a negative voltage, and to give some idea of the controlling factors.

R	V_E	$I_{E(calculated)}$	Vc
510	7.95	8.0 ma	-0.36
750	7.90	5.5 ma	-0.33
1k	7.89	4.1 ma	-0.29
1.2k	7.88	3.4 ma	-0.26
1.3k	7.88	3.2 ma	-0.24
1.5k	7.87	2.7 ma	-0.21



The data in the table are plotted in Fig. 2. This was necessary as it was not obvious from the table alone if there was an expected relationship. Actually, we had no real idea what to expect, but if we did, we probably would have supposed the collector voltage V_C would be proportional to current. Plotting V_C as a function of R gives Fig. 2a. Looks fairly linear! But, we were guessing linear with current – if anything.

Since we know V_E is approximately the Zener-regulated 7.9 volts, we can calculate the current I_E from R. This gives Fig. 2b, which is not linear. We do see that the voltage magnitude increases with current, as we expected. We are perhaps not disappointed to see that the output voltage level starts to level off with increasing current – it could never have kept just going up.

In the telling of the explanation offered by Pease, it was said essentially that just about any NPN could work. I'm not certain this is so. I probably have some real 2N3904 transistors on the premises, but what I used was from a lot (house number PN3) I have used for many years whenever a generic NPN was called for. I don't recall these ever not working as I desired. But in this case, V_C remained essentially zero! And the EB junction did to seem to Zener at an expected 6-8 volts, or was too high relative to supply.

Of course, when something fails, you try switching things around. (In fact, one failing was a loose ground return – but that did not fix things.) So you try other transistors. I have about three lots of more or less generic NPNs. A second lot (house number S7401) worked just find, giving the data in the table. So you put one from the first lot back in. Still does not work.

Here's why (apparently). The supply voltage specified was +12. With the EB junction Zenering at about +7.9 (data in table using S7401) things worked. What if the first batch had Zenering voltages even greater than +8? Well, just turn up the supply. When the supply reached +15 (better still, +20) the first batch (PN3) had reliable Zener voltages of about 9.8 volts. With a +12 supply, there was not enough current. With the EB junction Zenering, a measurable voltage appeared at V_C, although much lower than that from the second batch.

SO, WHEN DOING THE EXPERIMENT:

(1) Use +15 instead of +12.

(2) Have transistors of several types available.

All and all here we have an interesting "bar bet" type of puzzle to entertain our fellow EEs. It would be interesting to see if anyone has taken this further – or will.

PS:

After completing this as a draft, two issues remained. First, we never mentioned that from the Planet Analog description they say that putting any particular transistor in the Zener region may degrade its performance (reduce beta). So don't try a full batch!

Second, the description was not clear if this only worked for NPN. I thought it kind of suggested that. So I used a -15 supply with a PNP (house number 51A) and got it Zenering at -7.8 with a collector voltage of +0.32 (R=750 ohms). So I guess it works for PNP just as well.