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EEVblog Electronics Community Forum » Electronics » Beginners » How to REALLY measure hFE of NPN transistor?


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 **Author**

Topic: How to REALLY measure hFE of NPN transistor? (Read 11977 times)

0 Members and 4 Guests are viewing this topic.

☐ **wasedadoc**

Super Contributor



Posts: 1730

Country: 

 **Re: How to REALLY measure hFE of NPN transistor?**

« **Reply #25 on:** June 09, 2023, 08:27:04 pm »

One only needs to look at the schematics of transistor AM radios and see how AGC is implemented to confirm that gain varies with operating current.


 Logged

☐ **IanB**

Super Contributor



Posts: 12660

Country: 

 **Re: How to REALLY measure hFE of NPN transistor?**

« **Reply #26 on:** June 09, 2023, 08:40:29 pm »

The most important fact is that the "real" H_{FE} is the one that occurs under the circuit conditions of interest, when using the actual device under consideration. Any other number is simply an illusion.

 Logged

☐ **Zero999**

Super Contributor



 **Re: How to REALLY measure hFE of NPN transistor?**

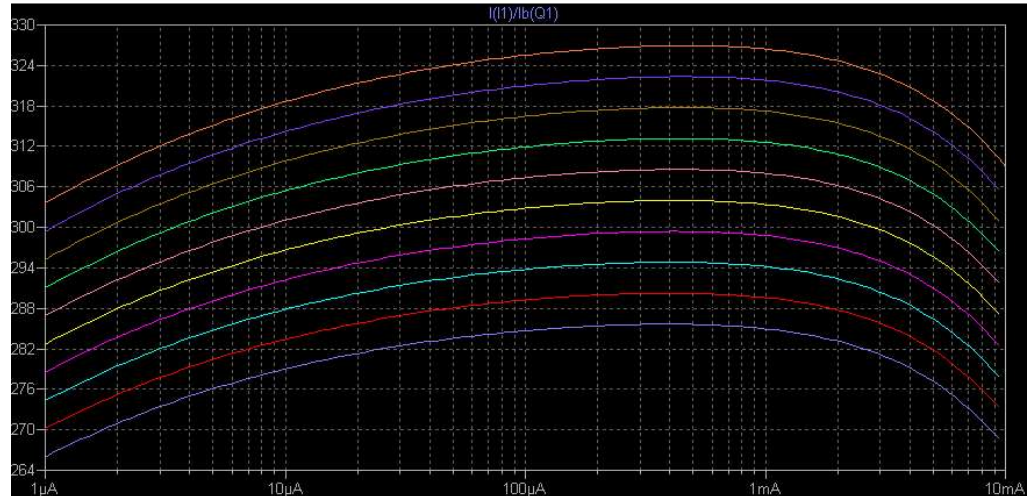
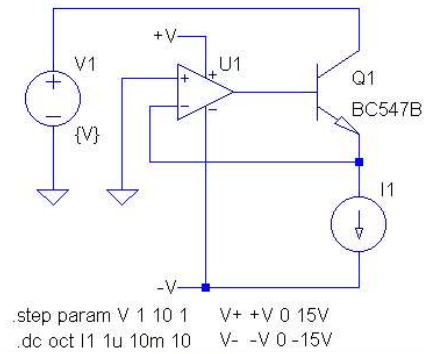
« **Reply #27 on:** June 09, 2023, 09:36:15 pm »



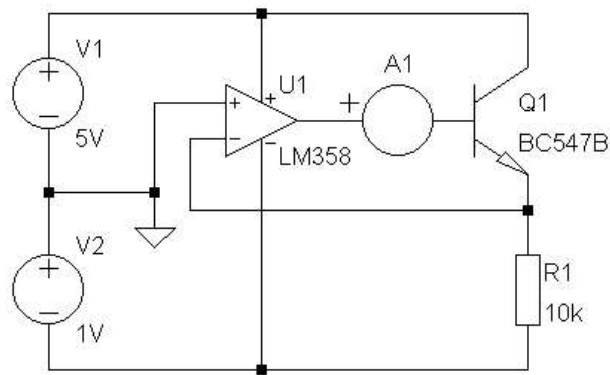
Posts: 21027
Country: 
0999

An op-amp can be used to set the voltage and current independently.

Here's an LTSpice simulation.




And a practical circuit.

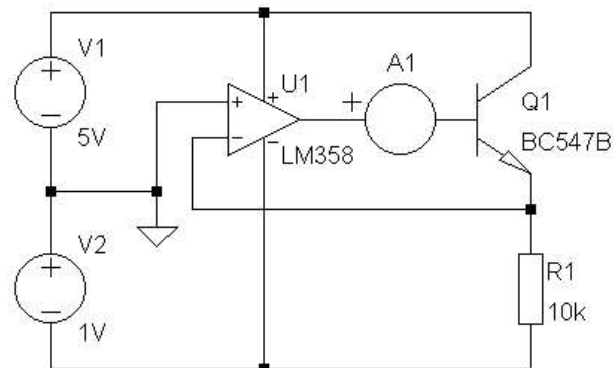


$$I = V2/R1$$

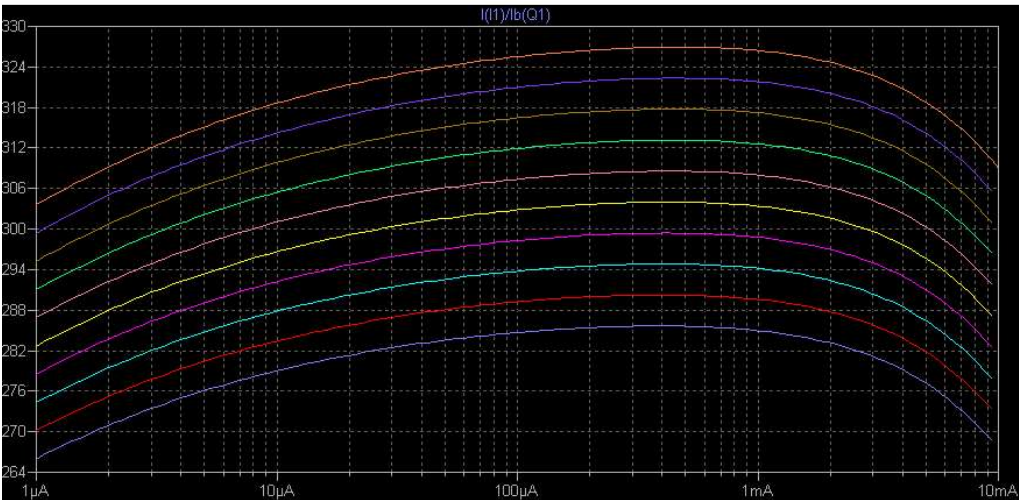
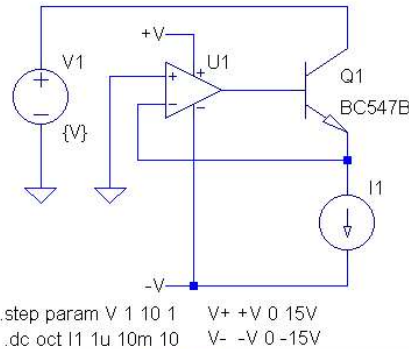
For the purposes of the test, I_C can be considered to be equal to I_E , since the base current is small.

Obviously $V1$ and $V2$ need to add up to the operating voltage specification of the op-amp.

 hFE Test.asc (0.88 kB - downloaded 103 times.)



hFE test practical.png (1.41 kB, 410x267 - viewed 1001 times.)



hFE test.png (11.85 kB, 874x737 - viewed 1057 times.)

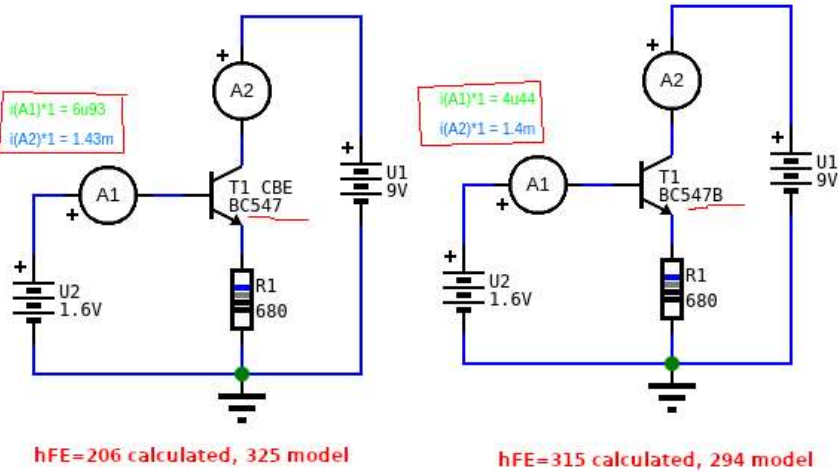
Logged

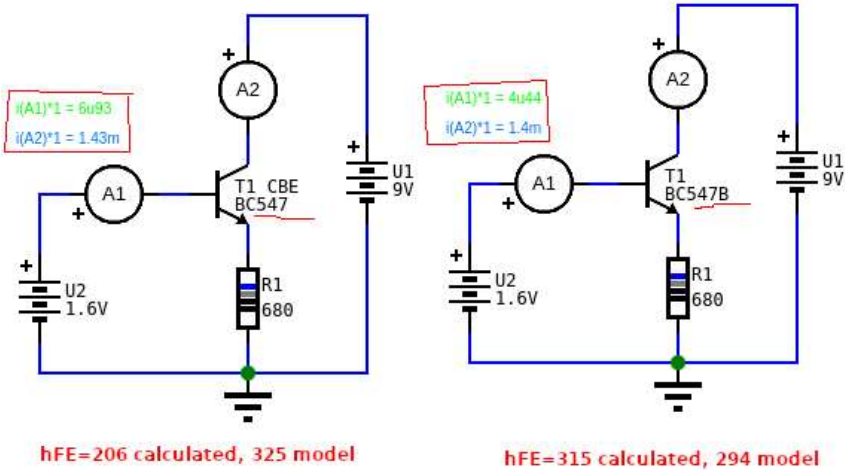
dusan
Regular Contributor
Posts: 113
Country:

Re: How to REALLY measure hFE of NPN transistor?

« Reply #28 on: June 10, 2023, 09:54:00 am »

Ok, so here is conclusion. I was using model of BC547 which had BF=325. No matter what method I used and what values I used, I could never get with hFE above 280. Zero999 used BC547B which has BF=294.3 and his charts showing hFE well above 300. I used his model and now I am able to get same result (315) which means I can now find a setting where hfe is exactly same as the model. I don't know which settings yet, but at least it is now theoretically possible, which is improvement.





screenshot-319.png (22.72 kB, 582x370 - viewed 1018 times.)

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MrAI

Super Contributor



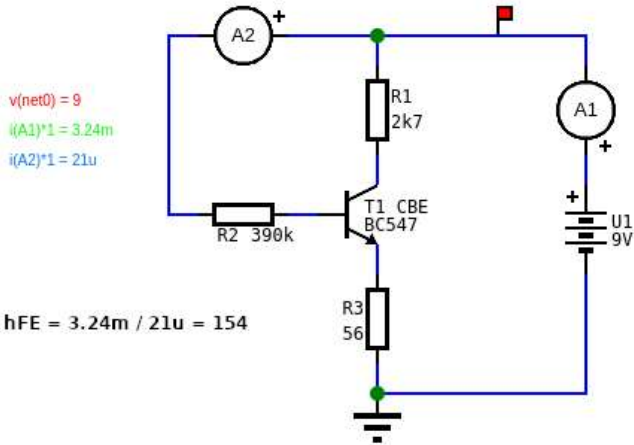
Posts: 1774

Re: How to REALLY measure hFE of NPN transistor?

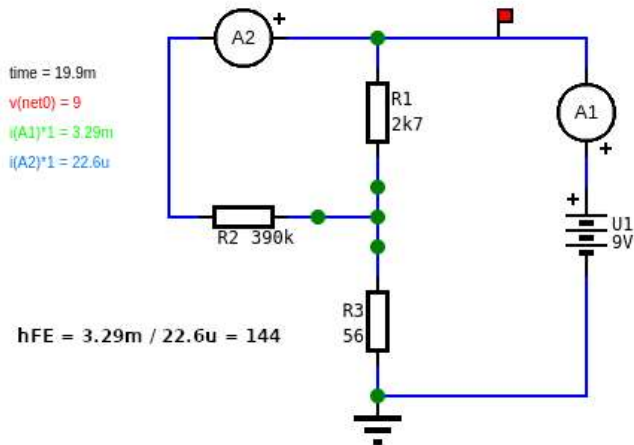
« Reply #29 on: June 10, 2023, 10:18:49 am »

Quote from: dusan on June 08, 2023, 06:43:27 pm

So I googled how to measure hFE using two ammeters and this thread came up:
<https://www.eevblog.com/forum/testgear/measuring-hfe-of-a-transistor-by-multimeter/> - OK, seems simple enough:



hFE=154, seems reasonable for BC547. Then I got brilliant idea to replace the transistor with short and the result:



hFE=144, that's really good for piece of wire. Before I head to the patent office, are there any better methods at measuring hFE?

Hi,

Not sure if anyone mentioned this yet, but the circuit with resistors means almost nothing except that if you had a transistor that acted more like resistors then you would get a false reading. Another example is when you measure the resistance of a diode. If the diode measures 100 Ohms, does that mean it's now a resistor. Certainly not, it only looks like that for one particular test current. If we vary the current we find that it does not work like a regular, fixed resistor.

In short, a transistor is not a set of resistors it is much more dynamic than that. When you replace the transistor with resistors you are no longer measuring the Beta you are measuring the currents into a three resistor network.

What this means is when a transistor goes bad its Beta is usually going to go off the charts. For example, a transistor that normally measures 100 will measure 10 or even lower when bad. That's one of the assumptions of this test.

In reality the transistor needs to be tested at several operating currents anyway. That means the input current has to be stepped from say maybe 100ua to 1ma to 10ma, and read the output current. The point where it enters saturation is also a good test, as well as the saturation voltage with different collector current levels.

The best test is to vary the input current from some low value like 10ua up to maybe 10ma (depending on the transistor) and measure the Beta spread. The Beta will change wildly with different input currents. A transistor that measures 100 will often measure just 10 when near saturation because the collector base diode becomes a little forward biased and therefore 'steals' some of the current from the base, meaning the external base current has to be higher than usual.

When we use simple, basic tests like this, we always have to live with some assumptions. If we are not willing to do that, then we have to move on to a much more sophisticated test or set of tests. The simpler tests work in most cases and are designed to be simple and fast.

If you really want to test a transistor completely, you've got a very long way to go. Even an automatic curve tracer isn't going to tell you everything. There are many, many more specifications that have to be tested.

« Last Edit: June 10, 2023, 10:21:58 am by MrAl »

Logged

☐ **Sredni**

Frequent Contributor



Posts: 746

Country:

Re: How to REALLY measure hFE of NPN transistor?

« Reply #30 on: June 10, 2023, 01:53:05 pm »

Quote from: dusan on June 10, 2023, 09:54:00 am

Ok, so here is conclusion. I was using model of BC547 which had BF=325. No matter what method I used and what values I used, I could never get with hFE above 280.

What values of current did you get in your original circuit (the one in the first post) when R2 is 2.2meg (and all other components are unchanged)?

Because your problem was definitely that you drove the BJT into saturation, and not some obscure model shenanigan.

Logged

All instruments lie. Usually on the bench.

☐ **dusan**

Regular Contributor



Posts: 113

Country:

Re: How to REALLY measure hFE of NPN transistor?

« Reply #31 on: June 11, 2023, 05:53:13 am »

BC547 - Ic 667uA, Ib 3.8u, hfe=175 (model's BF=325)
BC547B - Ic 1150uA, Ib 3.77u, hfe=305 (model's BF=294.3)

Logged

jeepe

Guest

Re: How to REALLY measure hFE of NPN transistor?

« Reply #32 on: June 11, 2023, 08:27:25 pm »

it'd be great if this conversation produced a cool method to measure hFE in the end...

most people, like myself, don't know much about transistors, actually...

but we would like to know that magic number...

so we could build a fuzz face based on some calculations... for example...

the problem is that different DMM-s will throw different numbers...
so trusting those numbers is like flying blind on some occasions...

MrAI's suggestion, however, to sweep over a large range of current values seems to open up some perspectives, doesn't it?

even if people could add the current value to the hFE value they measured would help... say hFE 178 @ 18microA... than that could be a reference for anyone else reading the report on a good sounding effect 😊
Measuring hFE at multiple current values would be even better...
one person's report could be used by others..
also, fuzz face calculators could be used more intelligently...
etc, etc..

 Logged

Kim Christensen

Super Contributor



Posts: 1819

Country: 



Re: How to REALLY measure hFE of NPN transistor?

« Reply #33 on: June 11, 2023, 08:36:06 pm »

Quote from: jeepe on June 11, 2023, 08:27:25 pm

even if people could add the current value to the hFE value they measured would help... say hFE 178 @ 18microA... than that could be a reference for anyone else reading the report on a good sounding effect 😊 **Measuring hFE at multiple current values** would be even better...

Well, that's the kind of info you'll also find in many datasheets like [this one for the 2n2222](#).
On page two, you will find "DC Current Gain" under the heading "ON CHARACTERISTICS" where it gives you a table of minimum hFE for different collector currents.
Then on page 3, there's a nice graph of the same sort of data but with more detail such as how temperature affects hFE.

 Logged

bdunham7

Super Contributor



Posts: 9039

Country: 



Re: How to REALLY measure hFE of NPN transistor?

« Reply #34 on: June 11, 2023, 08:41:41 pm »

Quote from: jeepe on June 11, 2023, 08:27:25 pm

it'd be great if this conversation produced a cool method to measure hFE in the end...

most people, like myself, don't know much about transistors, actually...

If you understand that h_{FE} isn't a single number and that it naturally varies according to conditions, then the methods of measurement will be fairly obvious. If you don't understand that, then I'd suggest you learn as it isn't all that complicated to attain at least a functional understanding of the transistor. You don't need calculus, quantum physics or Ebers-Moll (although the latter is worth a read even if you don't fully understand it) to get it well enough to make stuff.

https://en.wikipedia.org/wiki/Bipolar_junction_transistor

 Logged


A-3.5 digit 4.5 digit 5 digit 5.5 digit 6.5 digit 7.5 digit DMM is good enough for most people.

Zero999

Super Contributor



Posts: 21027

Country: 

0999

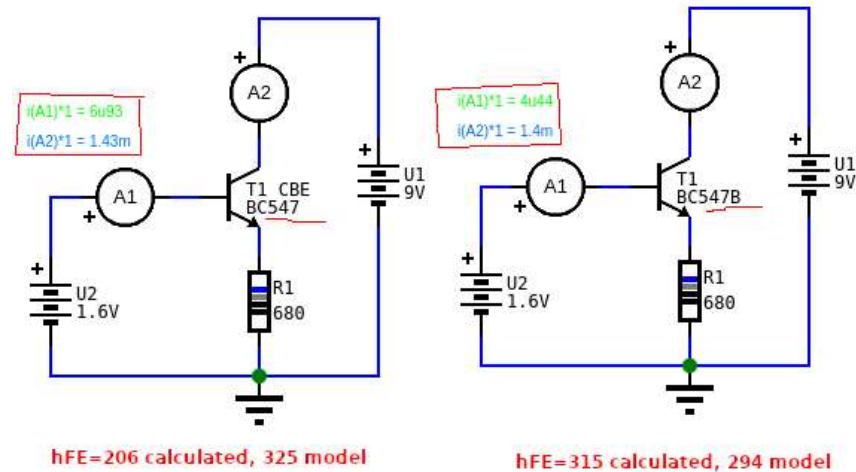


Re: How to REALLY measure hFE of NPN transistor?

« Reply #35 on: June 11, 2023, 09:06:14 pm »

Quote from: dusan on June 10, 2023, 09:54:00 am

Ok, so here is conclusion. I was using model of BC547 which had $BF=325$. No matter what method I used and what values I used, I could never get with hFE above 280. Zero999 used BC547B which has $BF=294.3$ and his charts showing hFE well above 300. I used his model and now I am able to get same result (315) which means I can now find a setting where hfe is exactly same as the model. I don't know which settings yet, but at least it is now theoretically possible, which is improvement.



Wait a minute: you've not actually tested it, only simulated it.

Do you know h_{FE} is also temperature dependant? This means it will change, as your circuit warms up. The good thing it has a positive temperature coefficient, but it's important to bear in mind, for low temperatures.

The bottom line is your circuit should work with the lowest and highest possible figures. The circuit I posted with base shorted to the collector, will give the lowest h_{FE} , for any given current, at the temperature under test of course.

Logged

TimFox

Super Contributor



Posts: 10072

Country:

Retired, now restoring antique test equipment



Re: How to REALLY measure hFE of NPN transistor?

« Reply #36 on: June 11, 2023, 09:20:53 pm »

In Spice, "BF" is the maximum value of beta for the device, not the beta at any other operating point. There are other parameters that determine how beta varies with the operating point.

Logged

wasedadoc

Super Contributor



Posts: 1730

Country:



Re: How to REALLY measure hFE of NPN transistor?

« Reply #37 on: June 11, 2023, 09:50:43 pm »

The actual hFE of an individual specimen of the transistor type number is of limited importance. Proper circuit design will ensure that the effects of variations between different specimens and of an individual specimen with temperature, current etc are not major factors impacting circuit performance.

Expressed another way. If you need to know the actual hFE that a transistor will have in your design, the design is suspect.

Logged

MrAI

Super Contributor



Posts: 1774



Re: How to REALLY measure hFE of NPN transistor?

« Reply #38 on: June 11, 2023, 10:06:50 pm »

Quote from: jeepe on June 11, 2023, 08:27:25 pm

it'd be great if this conversation produced a cool method to measure hFE in the end...

most people, like myself, don't know much about transistors, actually...
but we would like to know that magic number...
so we could build a fuzz face based on some calculations... for example...

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MrAI's suggestion, however, to sweep over a large range of current values seems to open up some perspectives, doesn't it?

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one person's report could be used by others..

also, fuzz face calculators could be used more intelligently...
etc, etc..

Hello there,

Yes that's an interesting idea. If everyone did this and contributed to the data base, we would have a list of actual test results for various transistors, which would not depend on the data sheet. Without that though we have to check out the data sheet and look for test values for the test we are doing.

I have to recommend at least 3 different base current levels are to be used, and they should be spread out like my example of 100ua, 1ma, and 10ma. We have to be careful though because if the transistor collector current goes too high and the voltage stays high, the transistor could blow out while testing it, which would be bad.

In many cases you can use a potentiometer to vary the base current. This makes it easier to set the current. When dealing with higher power transistors though that would not work unless the pot was rated for very high wattage, because we might have to input 100ma on some power transistors, maybe even more like 1 amp. That would mean we would need three power resistors for setting the base current.

It's not too hard to get an idea how the transistor is working though by just doing the test and not looking at any other data. If you see a gain of 100 with a normal transistor it's probably OK. Darlington transistors will of course have higher gain so maybe look for a gain of 500 or something. There are some transistors that dont have much gain so we would have to know that ahead of time. To add to that, when in saturation (with higher base current) the gain of a transistor with a normal gain of 100 could go all the way down to 10. That's a special case though.

The best thing to do is try this. Pick a common transistor like the 2N2222 or something and try testing it with three different base currents. It's not hard to do really. Experiment a little and see what you can come up with.

 Logged

 **bdunham7**

Super Contributor



Posts: 9039

Country: 

Re: How to REALLY measure hFE of NPN transistor?

« **Reply #39 on:** June 12, 2023, 01:33:38 am »

Quote from: MrAl on June 11, 2023, 10:06:50 pm

The best thing to do is try this. Pick a common transistor like the 2N2222 or something and try testing it with three different base currents. It's not hard to do really. Experiment a little and see what you can come up with.

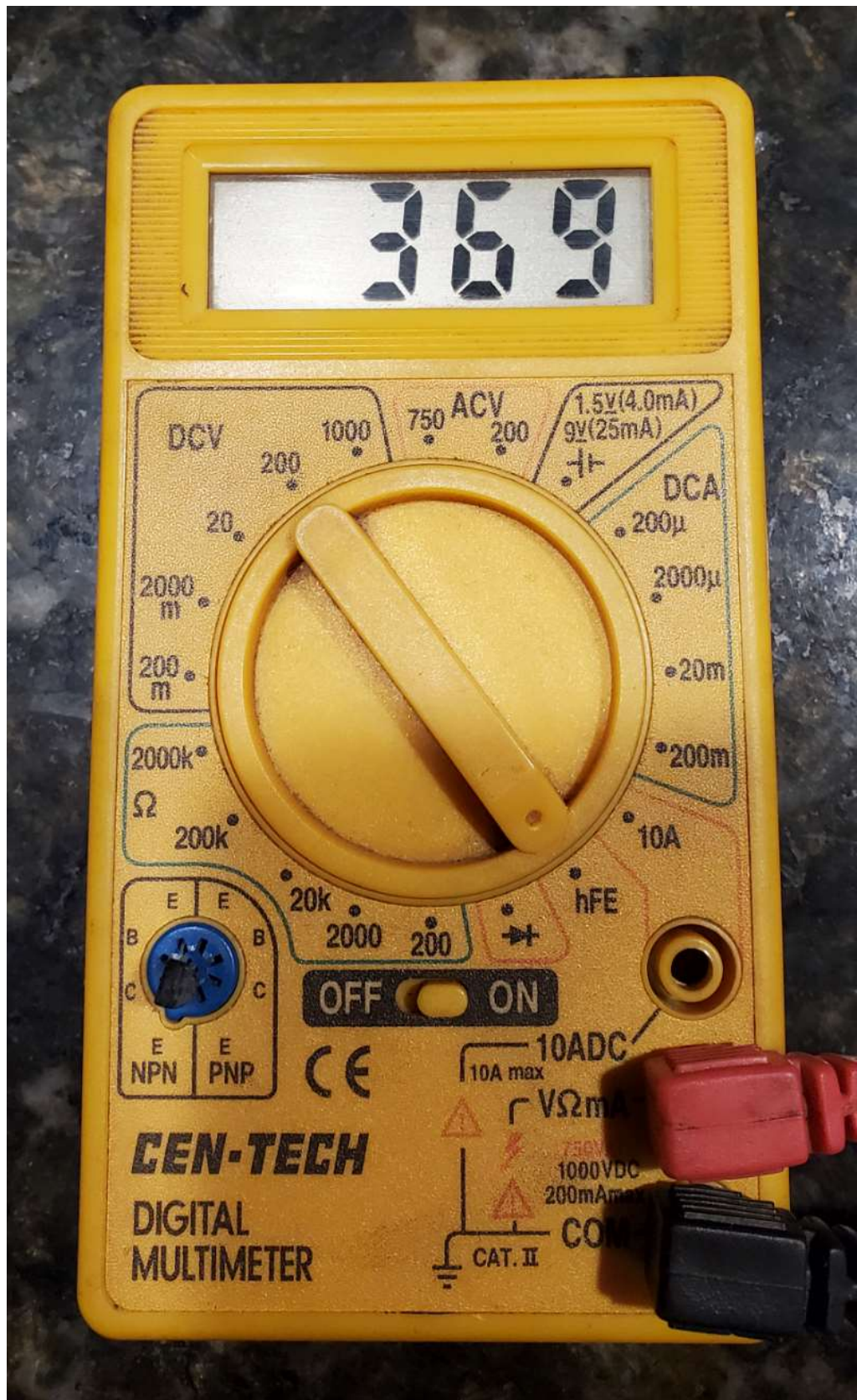
If you have a few things on your bench--a current-limited power supply and 2 DMMs, at least one of which uses fixed test currents for all or most of the resistance ranges and another that has a reasonably low current range, this is very straightforward. Set it up so the power supply goes through the current jacks of one DMM and then from C to E of the transistor. Then use the other DMM set to resistance to supply the base current from B to E.

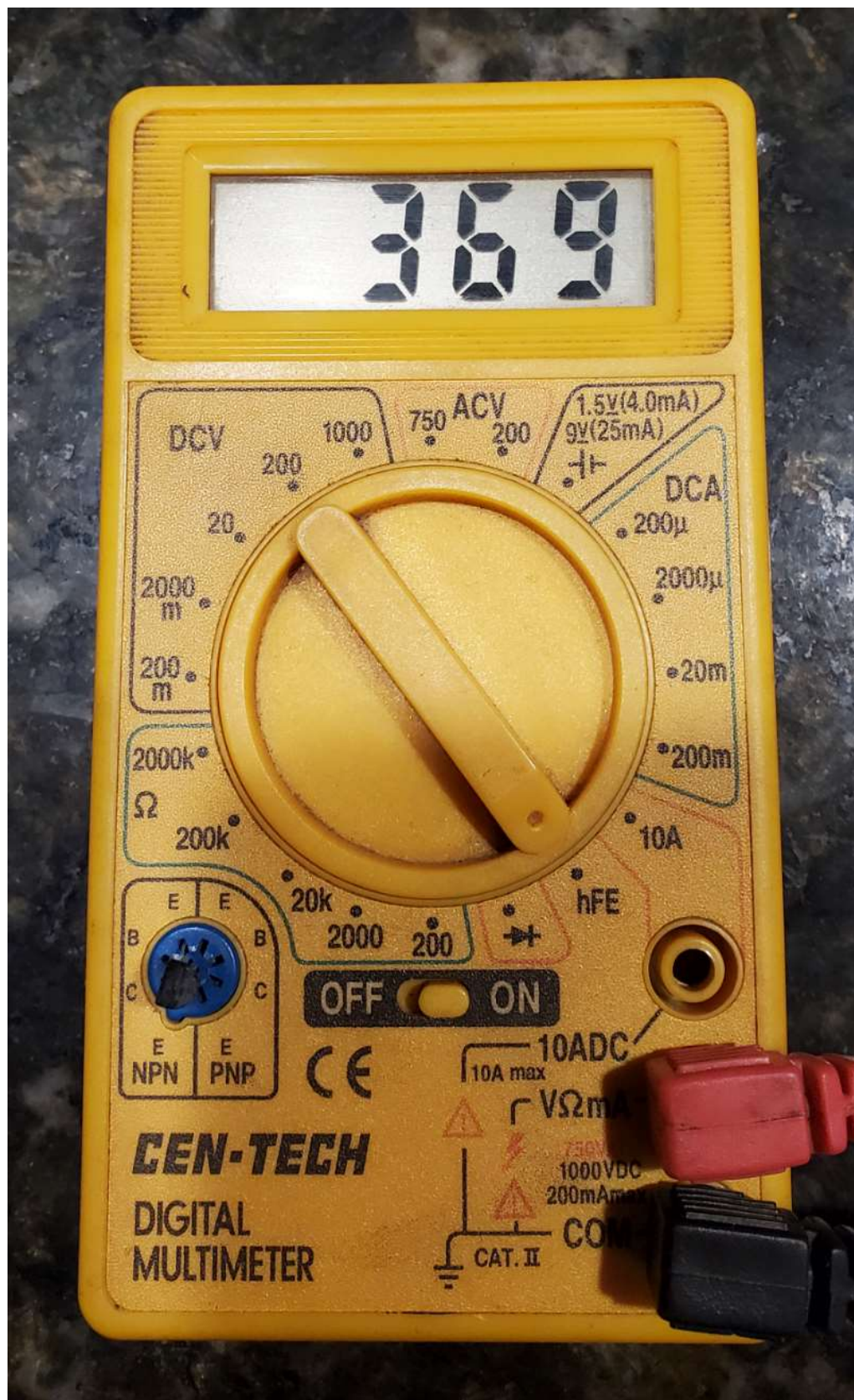
I use a Fluke 8842A which can give me fairly accurate test currents of 1ma, 100µA, 10µA, 5µA and 500nA which is probably adequate for almost all but the largest of transistors. I'll know if it is in the compliance range if I see a valid resistance indicated. Using this setup you can vary V_{CE} directly and easily calculate the gain for each step. A random 2N2904 gave me ~370 in the linear range, about 450 after I accidentally 'warmed it up' a bit and interestingly enough, a V_{CE} of only 0.11V with a 10mA current limit and 1mA base current (a 'forced h_{FE} ' of 10). V_{BE} was 0.71V in this case, so the collector is a full 0.6V below the base. With this setup you can easily tell when you depart the linear range because the PSU voltage, which is also V_{CE} since there is no dropping resistor, will start to drop.

Quote from: jeepe on June 11, 2023, 08:27:25 pm

it'd be great if this conversation produced a cool method to measure hFE in the end...

Plugging the same 2N3904 into a Harbor Freight 'free' meter gives me 369 and it varies with temperature (goes up with my finger on it) so perhaps this is the simpler answer to your question. The 'cool method' that can become your *de facto* standard is the DT830 h_{FE} function at 72F and with a fresh battery installed.





HF DT830 hFE 2N3904.png (1855.83 kB, 800x1315 - viewed 786 times.)

« Last Edit: June 12, 2023, 01:13:43 pm by bdunham7 »

Logged

A 3.5 digit 4.5 digit 5 digit 5.5 digit 6.5 digit 7.5 digit DMM is good enough for most people.

☐ **Sredni**
Frequent Contributor

Re: How to REALLY measure hFE of NPN transistor?

« Reply #40 on: June 12, 2023, 02:21:42 am »



Posts: 746
Country:

dusan
Regular Contributor

Posts: 113
Country:

jeepe
Guest

Quote from: dusan on June 11, 2023, 05:53:13 am

BC547 - Ic 667uA, Ib 3.8u, hfe=175 (model's BF=325)
BC547B - Ic 1150uA, Ib 3.77u, hfe=305 (model's BF=294.3)

In Microcap

BC547 - model BF=438 I get IB=3,75u, IC=1696u, betaDC=452.3
BC547A - model BF=191 I get IB=3.78u, IC=656u, betaDC=173.3
BC547B - model BF=294 I get IB=3.77u, IC=1055u, betaDC=279.3
BC547C - model BF=630 I get IB=3.75u, IC=1697u, betaDC=452.5

None of the above is saturated, they are all shown to be in LIN mode.
Your original circuit was at fault because it used too low a value for R2 and saturated the BJT. The values you get now are in line with whatever the actual beta for the currents should be according to the given model BF, it seems. (Each simulator has its own quirks on how to compute that, I guess, so there is no point in trying to get the same exact values between simulators).

Logged

All instruments lie. Usually on the bench.

Re: How to REALLY measure hFE of NPN transistor?

« Reply #41 on: June 12, 2023, 05:22:00 am »

Quote from: jeepe on June 11, 2023, 08:27:25 pm

it'd be great if this conversation produced a cool method to measure hFE in the end...

I've tested another method (in simulator). I checked all the equations for common collector and found that it's input impedance have beta in it's formula, so I measured the input impedance and derived the beta from it but it also didn't produced exact value as the model. But this is what I try next, take common emitter, common base and common collector, and find any formula that contains beta in it, and then try to use it to measure beta.

Logged

Re: How to REALLY measure hFE of NPN transistor?

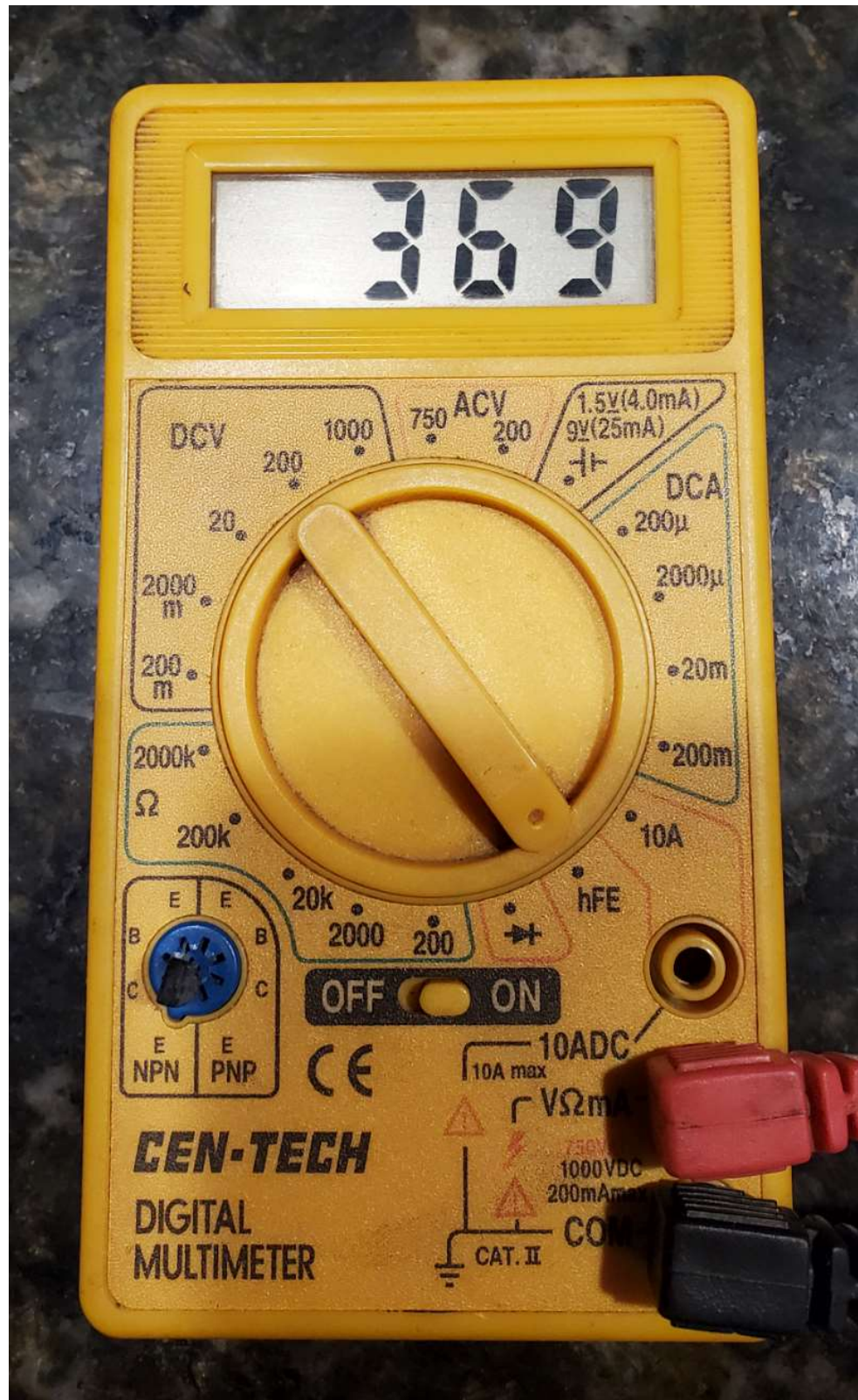
« Reply #42 on: June 14, 2023, 09:00:23 pm »

Quote from: bdunham7 on June 12, 2023, 01:33:38 am

Quote from: jeepe on June 11, 2023, 08:27:25 pm

it'd be great if this conversation produced a cool method to measure hFE in the end...

Plugging the same 2N3904 into a Harbor Freight 'free' meter gives me 369 and it varies with temperature (goes up with my finger on it) so perhaps this is the simpler answer to your question. The 'cool method' that can become your *de facto* standard is the DT830 h_{FE} function at 72F and with a fresh battery installed.



What's missing from your comment is whether your fluke will give you the same value (at any setting)... as the plastic DMM?

I remember arranging BJTs on a sheet of paper, drawing circles for heaps and writing down hFE values... and then, when using another plastic DMM correcting all those numbers... and taking some with me to a friend who had a more expensive DMM just to get still some different numbers...

Logged

☐ IanB

Super Contributor



Posts: 12660

Country:

jeepe

Guest

**Re: How to REALLY measure hFE of NPN transistor?**

« Reply #43 on: June 14, 2023, 09:21:09 pm »

Quote from: jeepe on June 14, 2023, 09:00:23 pm

What's missing from your comment is whether your fluke will give you the same value (at any setting)... as the plastic DMM?

But truly, the exact value is not supposed to matter. If a circuit design depends on the precise value of the transistor gain, the design is bad.

What is supposed to matter is the general magnitude of the gain, for example is it greater than 50, greater than 100, greater than 300? Almost any tester, applied appropriately, should be able to give you this value.

Logged

**Re: How to REALLY measure hFE of NPN transistor?**

« Reply #44 on: June 14, 2023, 09:23:17 pm »

Quote from: bdunham7 on June 11, 2023, 08:41:41 pm**Quote from: jeepe on June 11, 2023, 08:27:25 pm**

it'd be great if this conversation produced a cool method to measure hFE in the end...

most people, like myself, don't know much about transistors, actually...

If you understand that h_{FE} isn't a single number and that it naturally varies according to conditions, then the methods of measurement will be fairly obvious.

[...]

https://en.wikipedia.org/wiki/Bipolar_junction_transistor

Everybody understands that, that's the starting point. But this doesn't make the methods of measurement "obvious"...

But since I've described my aspect, seeking a way to be able to get a hFE measurement that can be relied upon, in terms of how a fuzz face actually sounds, instead of dropping a wikipedia link, which is a funny thing, cause this is now how knowledge actually works, you could have told me:

you've got a wrong approach... I mean, I...

and that this conversation is not a DIY group for building fuzz faces whatsoever, but an engineers' corner...

since I'm not an engineer -- because at one point I chose not to become that -- I see no point in reading your forum, not to mention asking questions 😊

the forum's look is what misled me...

the same as the freestombpboxes.org's... (the same software)

my bad,

bye

Logged

TimFox

Super Contributor



Posts: 10072

Country:

Retired, now restoring
antique test equipment

wasedadoc

Super Contributor



Posts: 1730

Country:

**Re: How to REALLY measure hFE of NPN transistor?**

« Reply #45 on: June 14, 2023, 10:11:34 pm »

What's wrong with my reply #10 above, refined by #13?

They give a way to "REALLY measure h_{FE} ".

Logged

**Re: How to REALLY measure hFE of NPN transistor?**

« Reply #46 on: June 14, 2023, 10:23:34 pm »

Quote from: jeepe on June 14, 2023, 09:23:17 pm

... seeking a way to be able to get a hFE measurement that can be relied upon ...

Surely it has been made clear in the replies above that any method which accurately measures base current and collector (or emitter) current can (by trivial arithmetic) provide an answer for hFE which is totally reliable as being correct for that transistor operating under the conditions at which the two measurements were made.

It is the same as a car's miles per gallon (or litres per 100 km) figure. You can do the test on your car but you will find that a single figure is not sufficient. The mpg varies with several factors including, but not limited to, speed, wind conditions, temperature, humidity, air con on or off, lights on or off, payload (occupants and luggage etc), tyre pressures, fuel octane, engine mileage, engine oil, service history.

Furthermore, if you repeat your test or tests on another car of exact same model under exact same conditions you will not get the same mpg figures. Might be close. But not exactly the same. Tolerances!

To paraphrase what I wrote earlier. If a ballpark figure for a transistor's hFE is not "reliable" enough then the design of the circuit it is to be used in should be modified. Might be as simple as adding a preset type variable resistor. Might be a different circuit configuration where some passive components with narrower tolerance, not the transistor hFE, dominate the circuit's performance.

« Last Edit: June 14, 2023, 10:29:40 pm by wasedadoc »

Logged

bdunham7

Super Contributor



Posts: 9039

Country:

Re: How to REALLY measure hFE of NPN transistor?

« Reply #47 on: June 14, 2023, 10:35:21 pm »

Quote from: jeepe on June 14, 2023, 09:23:17 pm

Everybody understands that, that's the starting point. But this doesn't make the methods of measurement "obvious"... But since I've described my aspect, seeking a way to be able to get a hFE measurement that can be relied upon, in terms of how a fuzz face actually sounds, since I'm not an engineer -- because at one point I chose not to become that -- I see no point in reading your forum, not to mention asking questions 😊

There are some things that simply can not be properly understood unless you take it upon yourself to acquire a certain amount of knowledge. The threshold isn't all that high here, but when you say this...

Quote from: jeepe on June 14, 2023, 09:00:23 pm

I remember arranging BJTs on a sheet of paper, drawing circles for heaps and writing down hFE values... and then, when using another plastic DMM correcting all those numbers... and taking some with me to a friend who had a more expensive DMM just to get still some different numbers...

...then the 'basic knowledge' that you have to acquire includes the fact that it is entirely possible that each of those DMMs gave you a completely correct number even though they were all different. Characterizing parts for applications where within-spec component parameters matter a lot--as your application seems to--is quite tricky and requires you to figure out an define what you are looking for. It's not a generalizable topic, so if you want to know any more, post a schematic of a specific fuzz face and perhaps someone can give you an idea as to what conditions h_{FE} should be measured.

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A 3.5 digit 4.5 digit 5 digit 5.5 digit 6.5 digit 7.5 digit DMM is good enough for most people.

IanB

Super Contributor



Posts: 12660

Country:

Re: How to REALLY measure hFE of NPN transistor?

« Reply #48 on: June 15, 2023, 01:48:48 am »

OK, this is weird, here is a link to a "modern" article about fuzz face circuits, published in 1998, and referring to the state of things 30 years before that (in 1968, when germanium transistors were still a thing):

http://www.geofex.com/article_folders/fuzzface/fffram.htm

The article points out that leaky transistors can completely mess up gain measurements, and you need to check for leakage before you try to measure hFE.

Apparently, the fuzz face circuit is deliberately designed to distort in an extreme manner, and depends heavily on the characteristics of the particular transistors used, to the extent that you have to carefully pick transistors from a batch to find the "sweet" ones (good distortion vs bad distortion).

Which makes me think that measuring hFE for this application is a bit futile. It would be better to build the circuit on a breadboard and plug in different transistors until you find the ones that sound good.

« Last Edit: June 15, 2023, 02:01:42 pm by IanB »

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MrAl

Super Contributor



Posts: 1774

Re: How to REALLY measure hFE of NPN transistor?

« Reply #49 on: June 15, 2023, 01:11:12 pm »

Hello there,

Measuring Beta is a common practice and gives you some idea about, well, the Beta. It's important to know if the transistor has enough current gain, that's the main thing. There are of course other tests, but the test for Beta is one of them for sure. Some people like to measure the gm and they are usually the ones that like to use gm instead of Beta for calculations. Spice models always seem to use Beta though.

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