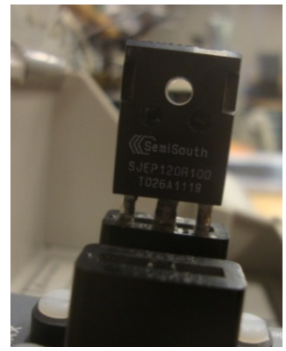
Is it a SemiSouth?



SJEP120R100. A JFET awaits trial by Curve Tracer. Is this really a good lie detector test?

A few weeks ago I posted a note on the DIYAudio thread www.diyaudio.com/forums/pass-labs/224122-sjep120r100-faking-china.html. At the time I said I would post some ideas on how to spot a genuine SemiSouth JFET from a potential fake. Time went by. Then more time. And then I finally decided to get the lead out. I had procrastinated enough.

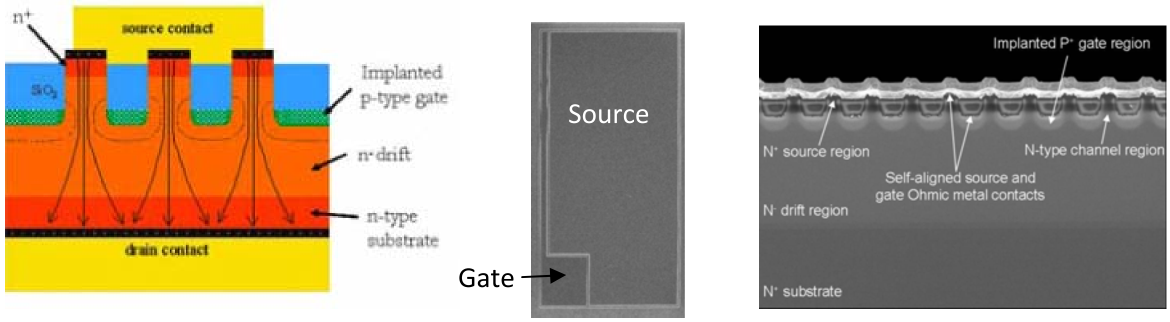
The thread first got my attention after it had become *the* spot to post warnings of fake SemiSouth junction field effect transistors (JFETs) soon after SemiSouth stopped production back in October 2012. It seems that offers to sell the SJEP120R100 had cropped up on the internet. (Big surprise, lol!) One or more sellers of apparent Chinese origin were selling parts assembled in TO247 packages with markings that, on casual inspection, identified them as some type of a SemiSouth "R100" variant. Images were provided in the posts of a knock-off device or two. Sharp eyes made observations about mistakes in the fine detail that revealed them as probable fakes. Upon reading I noticed that some of the comments were on the mark, and others were warnings that amounted to "false positives;" in other words, they warned of features that I knew were markings used on genuine parts by SemiSouth at one time or another.

Reading further, I gathered among the general warnings and some speculation that it might require tearing the package open to be sure it was not a fake. That, of course, would be self defeating if there really was a SemiSouth JFET inside.

That got me to thinking. What would I do if faced with sudden doubt about the authenticity of one or more of my parts? Was there really *SemiSouth Inside* that otherwise run-of-the-mil TO247 plastic package? How would I convince myself that it really was a 100-mΩ junction field effect transistor die having dimensions impossibly small (by the standards of silicon) to be rated at 1200 V while conducting 20 A with a mere 2 V drop, drain-to-source?

The more I thought about it, the more I realized it is not as simple as the game show Jeopardy where if I already know the answer, the question would not be so difficult to guess. Where I could just look at two or three things and then with a sense of reassurance that comes from already knowing the answer to begin with I could whisper under my breath "yep, that's a R100."

What if I didn't already know the answer? And what if there really WAS a semiconductor device of unknown type in that package? How would I know it was a SemiSouth JFET? I mean REALLY know?



The Beast? On the left is a cartoon showing three JFET "cells" formed by vertical channels. The source metal connects the three cells together at the top (image from R. Kelley et al. "Optimized Gate Driver for Enhancement-mode SiC JFET," *PCIM Europe*, 2011). The gates are connected together by a bus bar at the edge of the chip which can be seen on the left edge of a top view of the chip in the center. The drain is common to all JFET cells because it is formed by the SiC substrate itself. On the right is a cross-sectional scanning electron micrograph showing the real device structure of a SemiSouth SiC JFET (image from D. Sheridan et al. "Fast Switching (41 MHz), 2.5 m$\Omega\cdot cm^2$, high current 4H-SiC VJFETs for high power and high temperature applications," *ICSCRM*, 2005). A chip is a few millimeters on a side and consists of a thousand or more JFET cells all in parallel. Thus, every R100 is an example of a "massively parallel" JFET assembly long before Nelson Pass used the term in his latest article "The Beast with a Thousand JFETs" (see http://firstwatt.com/articles.html).

What should be in the package?

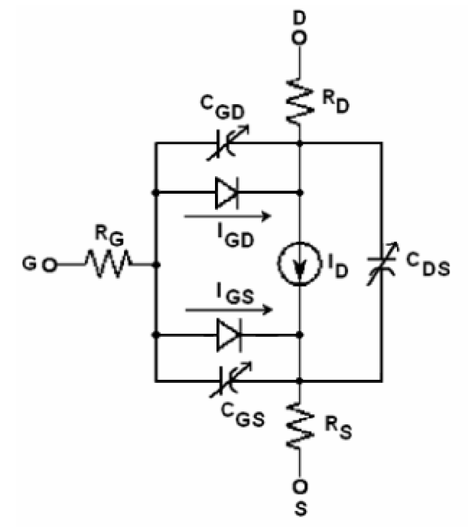
While not wanting to ask for too much time from a group of folks rightly more interested in their latest DIY build than my discussion of device physics, I thought I would begin with just a little bit of background on what SemiSouth put in those packages, both from an equivalent circuit stand point and from a physical device design and fabrication standpoint. I'll begin with the latter.

The SemiSouth SJEP120R100 is unique in that it is the only commercially released SiC field effect transistor with vertical channels, which resulted in industry leading low on resistance for the same chip size. The alternatives are the Lateral Channel JFET from Infineon and the Lateral Channel MOSFET from Cree and Rohm. New vertical channel "trench" MOSFETs and a new JFET are on the way to market as I write this, but SemiSouth was first. In the box above ("The Beast?") the inner construction of the SemiSouth JFET is explained in a bit more detail for those interested.

If we consider the outcome of this device construction, what we see is a massively parallel set of JFET channels with the textbook structure of an n-type channel surrounded on either side by p-type gates. This forms the gate-source pn-diode used to control electron flow through the channel. The addition of a lightly doped "drift" region electrically bonded to the conductive n-type substrate forms a second pn-diode in which the gate is the "anode" or "positive" or "p" terminal of the diode, while the drain is the "cathode" or "negative" or "n" terminal of the diode. This gate-drain diode is similar to the gate-source diode except it can block far higher voltage.

This is what the “n minus” (“n-”) drift region does: it creates a pn diode with excellent voltage blocking characteristics. The SJEP120R100 can block more than 1200 V (up to 1.8 kV is sometimes measurable) because of this n- drift layer and other features known as the edge termination which are not shown in the images.

The gate-source diode is not designed to block voltage. Instead, its job is to bottle up electrons near the source (hence the name) until an adequately positive voltage is applied to the gate that lets them escape the channel and enter the drift region. And that’s exactly what they do: drift toward the positively charged drain contact to which they are attracted because of the negative charge of electrons. They “drain” the FET there. The leakage current limitation of the gate-source diode is born of the structure and method of construction of the trench JFET. Chips that came off the production line with gate-source diodes that could block -15 volts without conducting too much leakage current (less than 300 μA) were sorted into the R100 bin, meaning that they satisfied the SJEP120R100 specification. Those that could keep the leakage current less than 300 μA at Vgs = -10 V but not -15 V were sorted into the “A” bin meaning that they satisfied the amended specification SJEP120R100A. Otherwise, the parts are identical. You can thank Nelson Pass for this amendment. When the company came to understand that the parts the audio community were buying would most likely never be used with negative bias (true for enhancement mode parts only, of course), then they had second thoughts about those die stuck in the higher leakage sort bins. That caused the company to spread the word that “A” meant Audio.



The guts of the matter. An equivalent circuit of a typical JFET, including the SemiSouth variety.

The structure of two diodes is reflected in the electrical equivalent circuit of the JFET shown in the box at the upper left (“The guts of the matter.”) and is a key feature of the SemiSouth JFET. I have tested hundreds of parts in my inventory in preparation to ship to DIY audiophiles who purchased them, always visualizing this equivalent circuit as I worked the curve tracer.

Is it a MOSFET? Is it an IGBT?

A curve tracer or if you are willing to accept some ambiguity even a digital multimeter can be used to discern that the gate, drain, and source are connected by two diodes. This can in turn be used to recognize certain device types as fakes. Two potential culprits are the silicon MOSFET and the silicon IGBT. Both of these common device types have fully insulated gates which cannot electrically act like the two diodes of the JFET. At most, a measurement of the forward or reverse gate-source (or gate-drain) leakage current of a MOSFET or IGBT will look like a JFET with an open gate. This condition is obviously not the sign of a *working* SemiSouth JFET!

While I have never come in contact with a fake SemiSouth JFET, it has been suggested on the DIYAudio forum that packaged working semiconductor devices have been sold with counterfeit package markings. I agree that such parts would be easy to procure and distribute from certain parts of the world. If the counterfeiter happened to choose an oxide-gated device, and meant it to be similar in specification to the original SJEP120R100, then they would probably choose a high-voltage IGBT rather than a MOSFET. This is because such parts are cheap and are in generic production in places where it is said the fakes are coming from. An IGBT, however, will always reveal its fake character by checking for gate-source and gate-drain diodes, the absence of which is your clue. So will a MOSFET, for that matter.

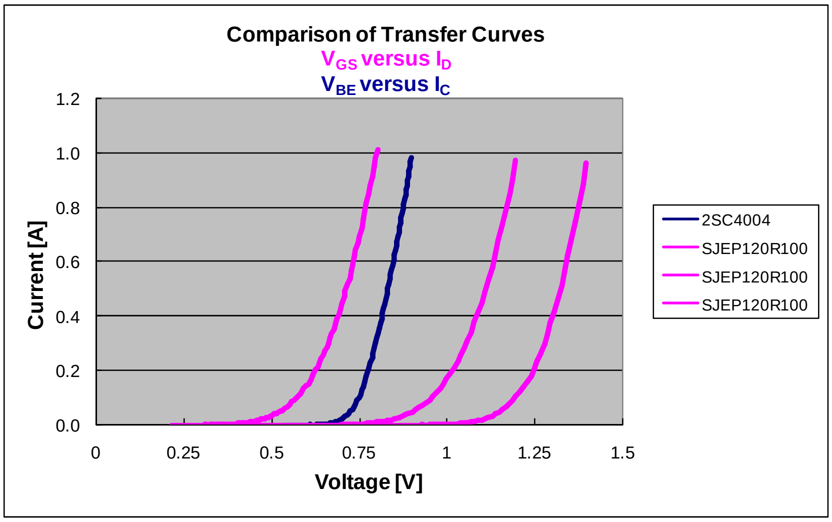
What if they are trying really hard to pass a fake for a JFET?

Again, I have no idea if the counterfeit surge has already come and gone, having not experienced the phenomena myself. But that is beside the point. I'm writing about *what if*. In that case, I have tried to imagine the toughest fake to detect from the terminals that might reasonably be out there. By asking the speculative question and then answering it (to the best of my ability) I could be accused of helping a future conspiracy. Kind of like why defense agencies around the world make nasty new weapons developments top secret; their first worry is that their own discoveries will be used against them. But in this case I think the risk is low, if for no other reason that even if a faker were rather crafty, it would still be pretty easy to detect their nefarious act using equipment a DIY'er is likely to have.

So what do I have in mind? To begin with, I'm not thinking the fake will be another JFET. There aren't any silicon types that can withstand the voltage and current levels readily available to the hobbyist to test with. There is a silicon carbide JFET made by Infineon, but as of this writing we still await Infineon making them available through any kind of reasonable distribution despite their claim last May that they are finally ready to take them to market. (The "Infineons" are nothing like a SemiSouth vertical channel JFET because they have lateral channels. I doubt the Infineons will be viewed as particularly useful in audio except by a hardy few that spend most of their time with burning amps.) From the faker's point of view marginal availability is not as important as the cost of SiC alternatives; anything SiC is way too expensive. Why bother with a life of crime if you are losing money? So, in the context of a "counterfeit part" in the usual sense, say, a low-grade bolt that is sold with counterfeit high-grade markings, there are no counterfeit SiC JFETs worth selling. The same goes for SiC MOSFETs and SiC BJTs.

Ah, but that last device type gives me pause. There *are* generic silicon BJTs in abundance and with ratings that could make it tricky to blast it with high voltage or high current to reveal its counterfeit character. Yep, real cheap ones too. High-voltage BJTs are used in commodity applications where even an IGBT is too expensive. For example, electronic fluorescent lamp ballasts. And if I got my trusty DMM out to check the terminals, what would I see? Uh, a diode there and a diode here, hmmm. If it were an *npn* BJT (what crafty faker would mess that up?) the fake would have the correct polarity, too. What do we do now, Batman?

Even a curve tracer might not be conclusive enough, at least at first glance. The specified threshold voltage range of a SJEP120R100 includes 0.75 V at the lower end. A comparison of three SJEP120R100 transfer curves with that of a 2SC4004 *npn* BJT in the box below ("Beware! A BJT could be hiding here.") illustrates the dilemma. If every part came out with an apparent



Beware! A BJT could be hiding here. The transfer curves of three SJEP120R100 parts selected from my inventory shows the range in threshold voltages that are possible. While the curve on the far left is outside of the data sheet specification, this part has better "triode-like" output curves than the parts that are within spec, meaning that this is an attractive part for audio. A 2SC4004 *npn* BJT is an 800-V, 1-A silicon transistor. The transfer curve of this device is clearly not the same as a SemiSouth JFET, but the differences are subtle enough to make it a real challenge to detect the fake from the real thing.

threshold voltage of about 0.7 V you might start to wonder. But then again you might have only a handful of the little suspects. This is a sophisticated faker, one who knows that if the price is too low it will be harder to pass. Your cost threshold may have left you with a small sample of parts and while the results may seem odd, they might still be that of a well matched quad of "*SemiSouth Inside*" JFETs. Maybe the forward leakage current into the "gate" looks a little high, but that is not often monitored during testing and even then, is it from a leaky gate or the base of a power BJT with decent beta? Like I said, this isn't Jeopardy, we don't know the answer in advance.

The answer, however, is at our finger tips. Some of you may already know what the trick is, or can guess. I could tell you right now without wading through a flash back sequence, and surely some of you will skip ahead anyway. (Most? LOL!) But to get the full understanding of why this sure-fire solution to the problem of separating a SemiSouth JFET from a common high-voltage BJT will work, I feel compelled to make an analogy. And for that, I need a flash back.

The time is the early 1980's in Norfolk, Virginia. My roommates and I are driving back to our very modest college home from the campus of Old Dominion University. It is around 5 PM and the traffic is snarled. We don't live that far from campus, but it is taxing our negligible twenty something patience to crawl home. Joe is driving. Bill is in the back. I'm shotgun. No matter what street we turn down, we end up back in the same mess. The combination of rush hour in a large city and bottle necks caused by the numerous tidal rivers and inlets that snake through Norfolk like the tidewater swamp that it is have left us with seemingly no options. Someone looks over and notices that there is one option after all: A boat ramp into a tributary of the Lafayette River. We quickly realize that near our home is another boat ramp off of the same river. All we need is a way to exit the road, "swim" to the next ramp, and then exit the river. For that we will need an amphibious car. This is something only engineering students with a bad case of wanting their afternoon six-pack of beer could dream up.

But it gets better. One of us (Bill I think) claimed that such cars exist. He remembers seeing one featured in a television commercial. We don't believe him. Bets are placed. A few days later, money changed hands. Back then, there was no internet. No iPhones. Nothing like ANY of this handheld techno stuff we have today. A person had to make a bigger effort to find out such things. It took longer. It required clever detective work. Bill brought a copy of the classified pages from the local paper to my attention. In that I saw the unbelievable. Not one but two Amphicars were for sale in Norfolk. Of course! Somebody else had had the same idea! We formed an Amphicar inspection team as soon as schedules would permit and in an old junk yard we laid eyes on our first Amphicar. I'm not making this up. You can still buy one off of ebay today. I gazed, with deadly serious eyes, on a real life Amphicar that I wanted to own, drive, and "sail." It had wheels where a car has wheels and propellers where a boat has propellers. I really wanted my own Amphicar.

Trouble was, it had been manufactured sometime in the 1960's and by the eighties it was an unseaworthy piece of junk. The rusted out holes in the chassis made it certain that this supposedly amphibious vehicle would sink upon christening, but after looking at the engine even that event would have required us to push it to the water's edge. I was characteristically optimistic. My friends were now no longer starry eyed engineering students. They were realists. No amount of nonsense I could think of would get them to budge. None of my friends were going to spend a dime on this wreck, and I had virtually no money to finance such foolishness. With a little time to nurse the disappointment, the Amphicar anti-traffic-jam fantasy went away.

Soon we were off on other distractions. Joe and I delved into our first "DIY Audio" project (long before I heard the term) by building a plasma loudspeaker. We won first place in the College of Engineering Open House. We discovered that our winnings ($100) did not cover the full costs of the gala victory party we threw (no matter). The Amphicar was left behind; and the beginnings of an interest in DIY Audio began. (Incidentally, the plasma loudspeaker was the subject of my first journal paper. Here's the reference if you have an itch to look it up: M. S. Mazzola and G. M. Molen, "Modeling of a dc glow plasma loudspeaker," *J. Acoust. Soc. Am.*, vol. 81, pp. 1972-1978, 1987.)

So what's this got to do with spotting a silicon BJT masquerading as a silicon carbide JFET? It's all about looking for the one thing that the imposter can't do. No matter how it is designed. No matter how it is built. What makes a duck a duck and not a chicken? Feathers? Nope. Wings? Nope. Flight? Yes. A regular car has got to stop at the water's edge. An Amphicar drives right in. That's what we will do with our suspect BJT. We'll take it to a curve tracer (or other suitable set up, see below) and make a measurement that will spot the BJT because it cannot do what a SemiSouth JFET can: Exhibit symmetrical SiC pn junction characteristics.

Measuring the forward conduction of the two internal diodes is a natural test for sorting a SiC JFET from a Si BJT. The former has a primitive molecule made up of one silicon and one carbon atom, but the latter does not. That cannot be easily counterfeited, at least in away worth doing by those with an economic motivation. The superficial similarity of the internal construction of the two types of devices (they both have anode-to-anode diodes) allows this to be measured and instantly observed with the same dirt-cheap and simple test set up that will allow an oxide gated device to be exposed as a silly fraud. Virtually everybody in DIY land will be able to do this test and it won't leave a shattered or even remotely damaged transistor when you are done.

There are two things we will be looking for that will leave us confident about what we have in the package. The first is the correct forward cut-on voltage. The second is symmetrical conduction in both junctions. To see why, let's spend a moment talking about semiconductors, bandgaps, and "built-in" potential. I promise there won't be a test at the end.

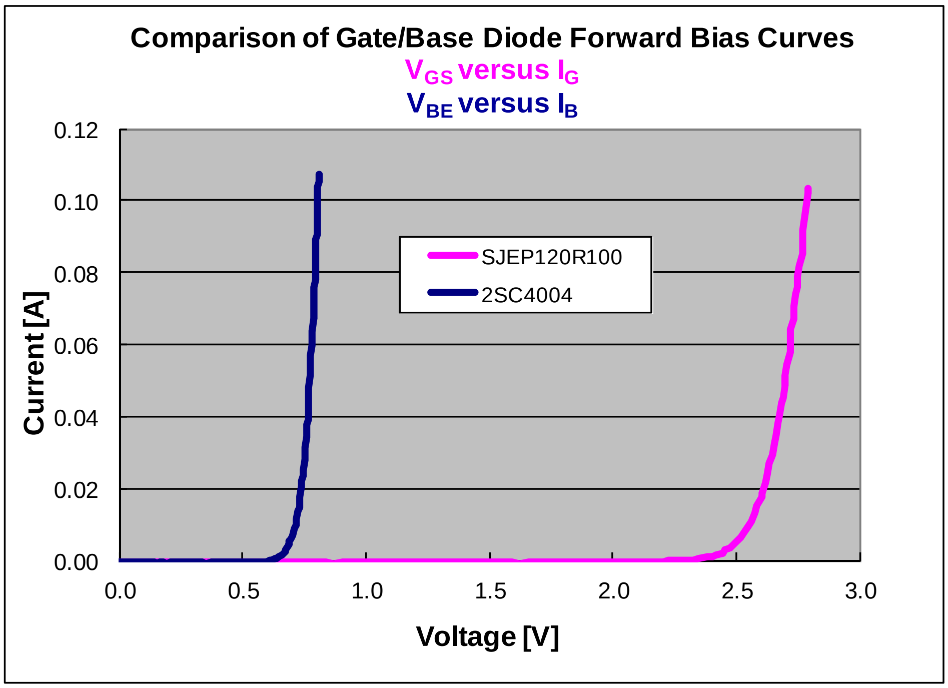
In one respect, a BJT and a JFET are cut from the same cloth. They are both formed of two pn junctions. A pn junction is characterized by the "joining" of two semiconductors. For a so-called "homojunction," which is the type in our R100 and assumed to be in our R100 fake if it is a common silicon BJT, the two semiconductors consist of a common material (i.e., silicon carbide or silicon) that differ in polarity. The gate is filled with positive charge carriers (hence "p") and the source or drain are filled with negative charge carriers (hence "n"). The same goes for our BJT except we call the "p" layer in a BJT the base, and the two "n" layers the emitter and the collector. Clearly, the terms "source" and "emitter" are synonymous, as are "drain" and "collector." But sometimes details matter so let's take a closer look.

Every pn-junction builds up an internal electrical barrier to intermingling between the numerous electrons on the "n" side of the junction and the numerous positively charged particles called holes on the "p" side of the junction. You can think of it like a big barrier of parents to keep teenage boys on one side from mingling with teenage girls on the other. We know what's behind the teenager's drive to mingle, but in the case of semiconductors, the impulse to wander is thermal energy. The barrier is nevertheless very real even if it is electrical in nature. We call the barrier the "built-in potential." Most DIY Audiophiles are doubtlessly familiar with the observation that a forward biased diode has about a 0.7 V drop. This seemingly constant forward voltage drop is a direct observation of the built in potential that is part of every pn-junction diode. What may not be so obvious is that 0.7 V is a generalization, not a law. The actual value of the built-in potential depends on a number of things, including temperature and the internal construction details of the diode, but most especially bandgap energy.

For our purposes, there are two main differences that can be observed by any DIYer with the normal test equipment. By "normal" I mean a digital multimeter with diode checking function or even an analog multimeter teamed with a power supply (to include a humble 9 V battery) and a resistor. It can be that simple. Of the two differences one is so big that it is impossible not to spot quickly. This is the difference that comes with replacing every other silicon atom in the pn junctions of our R100 JFET with an atom of carbon. Presto, we have one of the most remarkable semiconductors every invented: silicon carbide. Silicon carbide belongs to the class of "wide bandgap" semiconductors, and is among the most mature for use as a power semiconductor. So-called "narrow bandgap" semiconductors include silicon and gallium arsenide. The narrow bandgap semiconductors have not suffered for lack of width. The foundation of the late twentieth century technology revolution is anchored in the success of Moore's Law which is about silicon. All hail Caesar!

But as good as silicon is, silicon carbide is better at being a power semiconductor. The reason is the 3.4 electron-volt (eV) bandgap of 4H silicon carbide used in all of SemiSouth's JFETs. By contrast, silicon's bandgap is 1.1 eV. The difference is profound. No SiC pn-junction can have a built-in potential as low as 0.7 V. In fact, the built-in potential of all of SemiSouth's products is between 2.3 V and 2.5 V. Simply put, this is a feature no silicon diode in forward bias can fake. It's similar to the difference between my height (6'1'') and Michael Jordan's. He will win the slam dunk contest every time.

The diode checker on a common Fluke DMM is a handy way to check for the correct built-in potential. Touch the positive probe (red if plugged into the "+" terminal of my Fluke 16) to the gate and the negative probe (black if plugged into the "COM" terminal of my Fluke 16) to the source of your suspect JFET. If a voltage between 2.3 and 2.5 volts shows on the screen, it is probably SiC, and thus not a silicon BJT fake. The box below ("Sorting the wheat from the chaff.") shows a more exact way of seeing what's going on using a curve tracer to measure the gate-source forward bias characteristic of a genuine SemiSouth SJEP120R100 and a potent imposter in the form of a 2SC4004, which is an 800-V silicon BJT.



Sorting the wheat from the chaff. While no one would be fooled by the TO220F package that the 2SC4004 *npn* bipolar junction transistor is legitimately sold in (I found the one tested here in a drawer in my laboratory), this chip is characteristic of numerous generic high-voltage *npn* BJTs on the market, some of which are surely being sold in TO247 packages. Such a part would be a potent imposter for a genuine SemiSouth SJEP120R100 if marked as such and sold by counterfeiters to hungry DIY Audiophiles. Dropping a fake with a bit more current rating than the 2SC4004 into a Pass Clone would likely bias up ok if perhaps strangely off a bit (but remember the threshold voltage of genuine R100's can fall within the BJT range). Performance might not be what was expected and the fakes might be put on the shelf undiscovered by the DIYer confounded by the inability of their copy to deliver the sound they expect. As the curves above taken on a curve tracer show, a simple check of diode forward bias characteristics would have revealed in an instant the fraud.

A much more subtle but telling finger print of a BJT is the asymmetry of the built-in potential between the base-emitter pn-junction and the base-collector pn-junction. No BJT can live without this asymmetry (if it wants to be sold, that is), while no JFET needs it to function as a well optimized unipolar field effect transistor. A practical *npn* BJT will always have the heaviest concentration of electrons in the emitter, while the concentration of holes in the base will be less, and the concentration of electrons in the collector will be least of all. The practical result is that the built-in potential of the base-emitter junction is greater than the built-in potential of the base-collector junction, typically by at least 10 millivolts but even 100 millivolts or more is possible. In contrast, the JFET gate and the channel region in the vicinity of the gate is rather homogenous in a SemiSouth JFET. The result is the cut-on voltage of the gate-source junction is practically indistinguishable from the cut-on voltage of the gate-drain junction. A Fluke meter diode checker will measure this voltage to the nearest millivolt. In my experience with SemiSouth JFETs, it always measures the same gate-to-source and gate-to-drain cut-on voltage to within a millivolt or two, and usually they are identical.

Sink or Swim? Checking the forward bias cut-on voltage of the pn junctions of your SemiSouth JFET can give quick peace of mind that there is not a silicon BJT inside that TO247 package masquerading as a SemiSouth silicon carbide JFET.

Car or…	**Silicon or…**	**BJT or…**
		
Amphicar!	**Silicon Carbide!**	**JFET!**
		

The box above ("Sink or Swim?") shows in images the results of my check for these two characteristics that easily distinguished the silicon carbide JFET from the silicon BJT. For those who don't have a DMM with a diode checker, a battery and a few kΩ's resistance in series with the purported gate and source or gate and drain pins will reveal the same information.

In Summary…

I have no idea if the threat of counterfeit SemiSouth JFETs is much to worry about, but that shouldn't matter. Without using the one-time hammer approach, it's plenty easy to spot even a decent attempt at faking a SiC JFET with a silicon part. Following these simple guidelines should either give reason to your suspicion or peace of mind. If you want more peace of mind, a careful testing effort that compares the results with easily obtained data sheets is recommended. Naturally, the best first defense is to buy from someone you trust.

- A SemiSouth JFET always has two easily checked pn-junction diodes.
  - The gate will always be p-type and the drain and source will therefore be n-type.
  - Forward bias is observed with positive voltage on the gate and negative voltage on the drain or source.
- If the gate appears to be open, suspect a MOSFET or IGBT.
  - It is possible the gate is open on your JFET, but if it is, throw it away.
  - If you can put it in a circuit and it dc biases easily, the gate is insulating not open and thus it is not a JFET.
- If you drop a BJT into an amp and measure the bias, it can easily look like a SemiSouth JFET with threshold voltage (Vgs) on the low end. Simple checks can eliminate this possibility.
  - Check the forward bias cut-on voltage of either the gate-source or gate-drain pn diode. If it is between 2.3-2.5 volts, it is probably SiC.
  - If the cut-on voltage is closer to 0.7 V, it is probably silicon, but it is definitely NOT SiC, and thus it is NOT a SemiSouth JFET.
  - If the forward bias cut-on voltage does not measure the same gate-to-drain as compared to gate-to-source, it is probably a BJT not a JFET.

The part must not "fail" the above tests because if it does, it's a fake. But to be sure beyond a shadow of a doubt that it is a SemiSouth JFET, the part should be shown to your satisfaction to have other characteristics known to be true of a SemiSouth JFET. This can be as simple as observing that it biases right and sounds right in the amplifier based on your experience or on published results. Or perhaps you have above average test equipment. If so, measure some other properties (like capacitance) and check to see that they match up well with the data sheet.

For now, I doubt this will be necessary, as no silicon part is going to hide from the "sink or swim" tests above, and cheap silicon parts are likely all you need worry about if the counterfeiter even rises to the trouble of hiding their deed.

Happy listening!

Mike "Semisouthfan" Mazzola

If you have comments about this article or you would like more information about obtaining SemiSouth JFETs, feel free to contact me at michael.mazzola@impowersystems.com.

More reading…

http://www.diyaudio.com/forums/solid-state/228132-easy-way-identify-counterfet-transistors-3.html#post3333617