Testing Lateral Power MOSFETs

When preparing your DH-220 for upgrading it to the DH-220C, it is important to evaluate the condition of the existing lateral power MOSFETs in the unit before implementing the upgrade. These are robust devices and will usually be in working condition, but this is no guarantee. The DH-220 employs 2SK134 N-channel MOSFETs and 2SJ49 P-channel MOSFETs. The EIAJ uses “2SK” to identify N-channel devices and “2SJ” to identify P-channel devices. Hafler used house-numbered parts 571134 and 561049 for the 2SK134 and 2SJ49 MOSFETs, respectively.

If you intend to use the old lateral power MOSFETs from a working or non-working DH-220 or other Hafler MOSFET power amplifier, it is highly recommended to test them for shorts, functionality and operating gate voltage (V_{G_op}). The latter is defined here as the gate-source forward voltage at which the device drain current is 150 mA, which is the approximate quiescent bias current for each device in the amplifier. So-called threshold voltage V_t is related, but not necessarily numerically the same, since different manufacturers may define V_t at different, usually rather small, values of drain current. Threshold voltage is the forward bias gate voltage at which the MOSFET *begins* to conduct.

The MOSFETs in the Hafler amplifiers were matched as same-sex pairs; in other words, they were binned into several different bins in accordance with their operating gate voltage (threshold voltage in loose terms) at a given current. Single-digit bin numbers were usually stamped on the top of the package (sometimes no longer legible). It goes without saying that when doing the tear-down of an old amplifier that the MOSFET groupings must be kept as they were. For example, it cannot be assumed that the pair of N-channel MOSFETs in the right channel is matched to the pair in the left channel.

One should also be on the lookout for mismatched MOSFETs from an older or non-working amplifier. This could happen if one of the MOSFETs was previously replaced with one that was not matched to the original device of the pair. Sometimes such a mismatch will be evident from the matching markings on the device package. Measuring V_{G_op} here is probably a bit more reliable approach to confirm degree of matching.

The Hafler amplifier design is fairly tolerant of mismatch by the nature of the lateral MOSFETs, but if very large mismatches are discovered, the MOSFET pair may need to be replaced. The Exicon lateral MOSFETs are available in binned versions.

Care in Handling and Testing MOSFETs

The lateral power MOSFETs are one of the most costly and fragile components in the Hafler amplifier. Because the gate is insulated from the other terminals, it can float to a significant voltage level or ESD can charge it to a significant voltage level. The gate voltage relative to the source should not exceed about 15 volts in either polarity. Otherwise, punch-through of the thin gate oxide can occur. The usual ESD precautions should be taken. It can be helpful to have the gate shorted to the source by means of a clip lead or something similar when there is no need for a potential to be applied between gate and source.

Testing for Shorts and Verifying Pin-Out

Here we make sure that there are no shorts in the device and that we have a correct understanding of the pin-out of the device. The most common failure of MOSFETs is a short between any 2 or more of the pins.

The pin-out of the original Hafler power MOSFETs in the TO-3 package is illustrated in Figure 1, which is a bottom view. Unlike many power transistors where the collector or drain is connected to the can, the lateral MOSFETs in the Hafler amplifiers have their source connected to the can. Looking at the bottom, you will see the gate and drain pins closer to one end of the case. If you look at those when they are above the centerline, the gate will be on the left and the drain will be on the right.

The lateral MOSFET has an N-type or P-type channel connecting from the drain to the source. It is normally non-conducting in the absence of an electric field applied to it by a forward bias on the gate. The gate is insulated from the channel and should show as an open circuit when a voltage of either polarity is applied to it and either the source or drain.

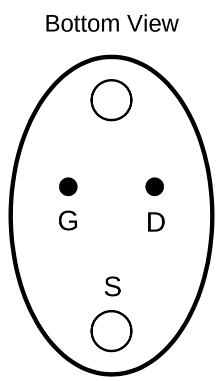

Figure 1: Pinout for the N-channel and P-channel Hafler TO-3 MOSFETs

If the gate is at the same potential as the source (e.g., by connecting them together) a measurement from the drain to source when a voltage of the normal operating polarity is applied will look like an open circuit. This may not be true if the gate is left floating. The normal operating polarity for an N-channel device is for the drain to be positive with respect to the source. It is the opposite for a P-channel device. If instead the ohmmeter applies a voltage opposite of the normal operating polarity, conduction through a diode drop will be observed, since there is a reverse diode junction from drain to source as part of the MOSFET device structure.

A word about ohmmeters, diode testers and continuity testers is in order. When testing semiconductors with these devices it is usually important to know the polarity that the meter is applying to the device under test (DUT). This is because some of the tests will be testing semiconductor junctions where current flow depends on the applied voltage polarity. In particular, you cannot assume that an old-fashioned non-DVM passive battery/meter ohmmeter applies a positive voltage from its red probe. In most, in my experience, the red probe in such passive ohmmeters applies a negative voltage. That voltage (open circuit) is usually the battery voltage in the ohmmeter, which often will be 1.5V or 9V, depending on the range and whether the ohmmeter has a 9-V battery.

If there is any doubt, test your meter's polarity by measuring a silicon diode like a 1N4148 or 1N4004. The probe applying a positive voltage will show junction conduction when that probe is connected to the anode of the diode. Thus, with a passive ohmmeter, you will often see conduction when the black probe is connected to the anode and the red probe is connected to the cathode. In such a case where the junction is conducting, the meter will often register about ¾ full scale or higher (but not full-scale) for a forward-biased junction. The reading only goes up to about ¾ scale because of the forward voltage drop of the silicon junction, often on the order of 0.6V. If you try this test with a Germanium diode, like the 1N34, the needle will go further up the scale because the junction drop will be less. This will be similar for different ohmmeter scales.

When testing with a typical DVM on its diode-check setting, you will usually see evidence of conduction or not, depending on applied polarity. For most DVMs, the red probe will be positive. In the diode-check mode, many DVMs will apply an open-circuit voltage greater than 1.5V, enough to turn on a silicon junction. On the ohmmeter range, some DVMs will only apply several hundred mV, which may not be enough to show a lot of conduction with a silicon diode. I personally have always preferred to use an old-fashioned passive multimeter on its ohms range.

Going forward, we will refer to the positive and negative leads of the tester, rather than the red and black leads, so as to cover either type of ohmmeter or diode tester.

For an N-channel lateral device, connect the gate to the source. Do not let the gate float. Connect the positive lead to the drain and the negative lead to the source and observe an open circuit or high resistance (e.g., maybe 50k on the 1k scale of a passive ohmmeter). Reverse the leads, putting a positive voltage on the source, and observe conduction that is consistent with a diode drop. This verifies that there is no drain-source short and that you have the pin-out correct. Do the same for a P-channel device, with the polarities mentioned above reversed.

Connect the drain to the source. Connect one lead of the tester to the source first. Then connect the other lead to the gate. An open circuit should be observed. Do the same with the leads reversed and once again observe an open circuit.

Testing for Functionality

For an N-channel device, connect the negative lead to the source and the positive lead to the gate and observe an open circuit. Doing this puts a positive charge on the gate that will be retained. Now connect the positive lead to the drain and observe conduction as a result of the forward bias remaining on the gate. This test depends on the measuring device putting enough forward bias on the gate to cause conduction above the threshold voltage. This will usually be the case for lateral MOSFETs because they tend to have fairly low threshold voltages. This often will not work for vertical MOSFETs because they usually have higher threshold voltages. For P-channel devices, use the same procedure, but with reversed polarities.

Measuring V_{G_op}

For measuring V_{G_op} of a lateral MOSFET, you will connect drain to gate, so as to forward bias the gate with the same potential as is on the drain. Some call this "diode mode". Connect the source to the ground of a power supply. Connect the power supply output through a 100-ohm, 5-watt series resistor to the drain. Turn on the power supply and increase its output voltage to 16V. If the gate and drain are at about 1V under these conducting conditions, about 150 mA will flow, and the actual voltage on the drain and gate will correspond to V_{G_op} at roughly 150 mA.

Current Production Alternatives

If one or more of your MOSFETs has failed, all is not lost. Although the original 2SK134 and 2SJ49 are obsolete, Exicon (exicon.info) sells the ECF10N20 and ECF10P20 as the TO3 equivalents of the 2SK134 and 2SJ49, respectively. Exicon also sells these devices in matched pairs with the “S” suffix.

MOSFET Matching and Verification

If you cannot obtain matched pairs, here is a simple technique for matching parts or verifying that they are matched. This can be especially useful if you have obtained a used DH-220 that has been repaired and had one or more of its MOSFETs replaced.

Measure the gate voltage required to cause the MOSFET to operate at the nominal quiescent bias current of 150 mA. This is V_{G_op} whose measurement was described above. Pair parts with the closest V_{G_op}. How close? The discussion below should help to answer this question.

Since V_{DS} is low in the V_{G_op} test, it is not representative of real-world operation, so this test is only useful for relative matching of devices. Typical readings for the N-channel device in this test are 0.9-1.1 V. Typical readings for the P-channel device are 1.1-1.3 V. This represents a small sample of parts, so do not be worried if your parts fall outside these ranges. In my experience, on a given amplifier channel, a pair of devices from a working Hafler amplifier tended to match closer than 100 mV. However, the amplifier is probably somewhat more tolerant than 100-mV matching. Hafler had a lot of parts to work with, so it was fairly easy for them to bin them to match more closely than absolutely necessary. Because of their negative temperature coefficient of drain current, the lateral MOSFETs are fairly forgiving of minor offsets between devices that are connected in parallel.