

Practical Mosfet Testing for Audio

by Nelson Pass, (c) 2003 Pass Laboratories

Introduction

The quality of individual parts is a particular concern to audio “do-it-yourselfers” (henceforth known as DIYers). Many of them lay awake at night agonizing over choices of capacitors, resistors, wires, and so on, in the belief that the characteristics of these passive parts greatly influences the quality of sound passing through the circuit. Maybe so.

But what about the active components? If there is anything that the objectivist and subjectivist camps should be able to agree on is that there is considerable difference between different active gain devices and that they produce measurable, if not audible results.

As a minimalist, I personally like to work with Mosfets, and I do so because they give me the most performance with the fewest parts. It is my experience that particularly with simple circuits and minimal feedback, the specific character of the individual Mosfet makes a real difference.

With that in mind, we set out to measure some of these parts and see if we can select the best for use in the signal path.

What is a Mosfet?

First off, a Mosfet is an electronic amplifying device, more specifically, a transistor. It is a little part that has three connecting pins coming out of it, known descriptively as the Source, the Drain, and the Gate. Using a hydraulic metaphor, if you think of the Mosfet as a faucet, then the Source and Drain are what the water flow through, and the Gate is the lever that turns the flow on or off, fast or slow. Except, of course, that the water is electrons, and the lever is operated by electronic charge.

Continuing the water analogy, assuming that there is some water pressure (voltage) across the faucet (transistor), then water (electronic current) will flow through it when the valve is turned on (the Gate is charged with voltage). In the case of a Mosfet, if there is Drain pin voltage relative to the Source pin voltage, electric current will flow from

the Source to the Drain if there is enough voltage placed between the Gate and the Source.

There are two basic kinds of Mosfets, the N channel and the P channel types, differing by the voltage polarities they work with. In the case of an N channel Mosfet, we can make a fine operating example (that you can do yourself) by attaching the Source pin to circuit Ground, a positive voltage source to the Drain through a current meter, and a variable positive voltage source to the Gate. In this case a potentiometer from V+ to ground with the wiper at the Gate. (Figure 1)

When the potentiometer is at full counterclockwise, the Gate voltage is at 0 volts (grounded as we would say) and no current flows through the transistor. As we turn the potentiometer clockwise, the voltage on the Gate becomes positive with respect to the Source pin and current starts to flow from the V+ of the power supply to ground through the transistor. The higher the Gate voltage, the more current. The less Gate voltage, the less current. The point of conduction varies from device to device,

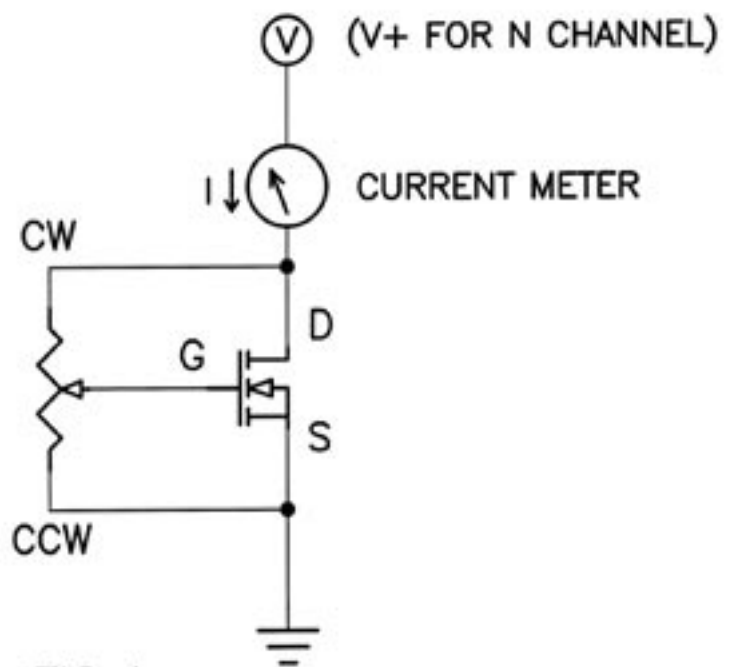


FIG 1
SIMPLIFIED TEST SETUP

but current will start flowing anywhere from about 2 to 5 volts on the Gate.

Practical lesson 1: If you turn the potentiometer sufficiently clockwise, you may hear a popping sound and smoke will come out of the Mosfet. If you're lucky. For this reason, I recommend that you keep an eye on the current meter when you try this.

The P channel device works the same way, but with the Drain at V- instead. The existence of both N and P polarity devices in transistors is very handy, and gives them a big flexibility advantage over tubes, which have only the "N" characteristic.

The Three Ways

As with the other three pin gain devices, there are only three ways to hook up and use a transistor. With a Mosfet they are known as Common Source, Common Drain, and Common Gate.

Figure 2 shows three examples. In the Common Source example the signal goes into the Gate, the Source is grounded, and the signal comes out the Drain with its polarity reversed and both its current and voltage amplified. The input impedance is high, and the output impedance is essentially the value of the Drain resistor.

Notice in Figure 2 that I have gone to the trouble to indicate phase of the output signal with a little "sine wave" icon next to the output. Of the three ways, only Common Source reverses the phase.

Common Drain, also known as a Source follower, is where the input signal goes in the Gate and the Source pin follows it, providing current gain, but not voltage gain. The output voltage is almost the same as the input voltage. The input impedance is high, and the output impedance is fairly low, being the inverse of the transconductance figure of the Mosfet.

Common Gate, usually seen as a "cascode" connection, is where the signal goes into the Source pin and comes

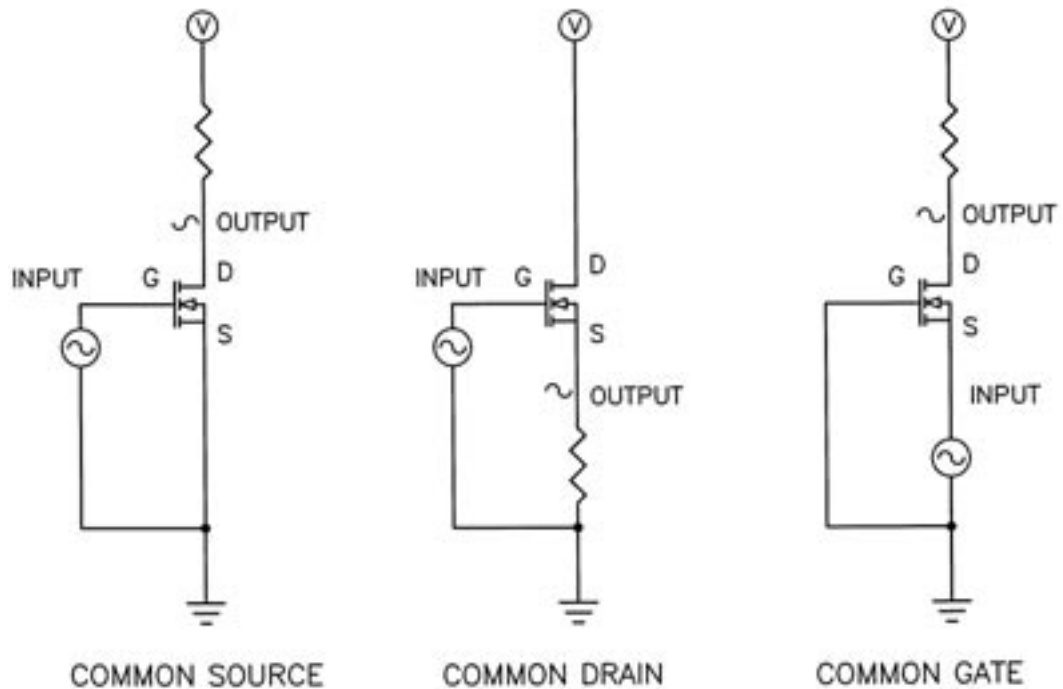


FIG 2 THE THREE WAYS TO USE A MOSFET

out the Drain. This connection has no current gain - the output current equals the input current. It can produce output voltage gain in phase with the input. The input impedance is the inverse of the transconductance of the Mosfet, and the output impedance is the value of the Drain resistor.

Of course the transistor itself has no idea how you are using it. It blindly reacts to the variations in voltage and current on its pins without any true knowledge of its place in the scheme of things. We all experience something like this now and again.

If you reverse bias on the Drain and Source, the ordinary Mosfet will behave like a Silicon diode, that is to say if you take an N channel device and put positive voltage on the Source and negative on the Drain, current will flow, and you'll see something like .7 volts Drain to Source. P channel devices, of course, do the same thing with opposite voltage polarity.

What Characteristics Are There?

Mosfets come with numerous numbers describing their characteristics:

Operating Wattage (Chip temperature) - How hot can you run it?

Maximum Voltage (pin-to-pin) - What voltages between pins will break the chip?

Maximum Current (Drain-to-Source) - What high current will melt the connections?

Current vs. Gate-Source Voltage (V_{gs}) - What is the specific gain character?

Gate Capacitance - The input Gate resistance is nearly infinite, but the Gate capacitance is substantial and often non-linear.

There are tons more numbers, enough to fill four to ten pages with lists and charts and graphs for each type of device. International Rectifier seems to be the dominant supplier of power Mosfets, and such information can be seen at their web site www.irf.com

So what characteristics are important? Let's look at the data sheets of one of my favorites, the IRFP240, an N channel power transistor in a plastic case.

First off, it's rated at 200 Volts Drain-Source (that's good) and a maximum current of 20 amps (also good), and a maximum wattage dissipation of 150 watts (case temperature at 25 deg C. The maximum voltage between the Gate and Source is 20 Volts.

These are important specs for selecting such a device, but you can pretty much figure that we aren't ordinarily going to be testing them, as we are not usually looking to break

the part.

As we go down the long list of numbers, some of interest for linear audio stand out: V_{gs} , the "threshold Gate voltage" where conduction starts (anywhere from 2 to 5 Volts), the Transconductance (somewhere between 0 and 12, depending), and the Gate capacitance (anywhere from 1200 to 2400 pF, also depending). These figures vary with voltages, current, temperature, and also by device. (I would reproduce these figures and curves here, but we don't have that much space, and I'd just as soon not have to deal with IR for permission). The transconductance is measured in Siemens, and is simply how many amps more flow from Drain to Source for each additional volt on the Gate-Source pins.

The Gate capacitance is important, for while the input impedance looks close to infinity at DC, there is what looks to be a capacitor of quite a few picoFarads attached from Gate-Source and Gate-Drain, both of which start creating a load at high frequencies for whatever is trying to drive the Gate.

Distortion? Not mentioned.

It is clear, however, that if you want to know what the performance will be for a given device in a circuit, you would best be measuring it yourself, not only because the manufacturer is not likely to be duplicating your exact circuit, but also because there is often wide variation between devices.

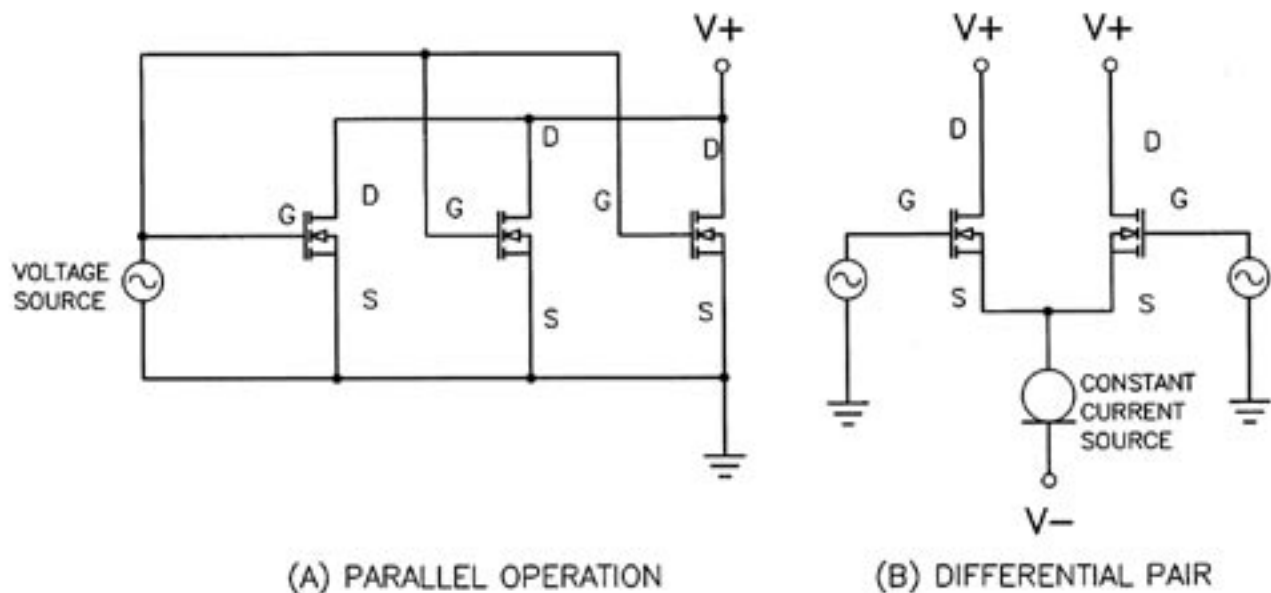


FIG 3 CIRCUITS THAT LIKE MATCHED PARTS

Why match?

Often the reason for measuring Mosfet characteristics is to match devices to each other. Most often this consists of measuring the V_{gs} of the devices, and occasionally extends to measuring the transconductance.

In the case of a power output stage, we often want to parallel power devices so as to share the current and heat dissipation, as in Figure 3a. Here it is desirable that the devices be identical so that the current is shared equally. If the V_{gs} of each device is different, some device will find itself doing the disproportionate share of the work while some other device might not be turned on at all. Even if the V_{gs} is matched at a given current for all devices, they might vary at different currents, so we either want to sample and match V_{gs} at different current and temperatures, or perhaps simply measure and match the transconductance at the operating point and cross our fingers.

A popular way around this is to match V_{gs} between devices having the same manufacturing lot code, meaning they were made at the same time under the same circumstances. This technique is very effective, and if you sequentially measure the V_{gs} of a batch of smaller chips of the same lot code, you can actually visualize the position of the particular chip on the silicon wafer by the V_{gs} pattern that develops. These devices are usually extremely well matched in all characteristics.

The other part of a typical amplifier circuit where matching is important is the circuit of Figure 3b, the “input differential pair” which compares the input signal to the amplifier’s output signal and amplifies the difference. This is known as feedback. Matching of these parts allows for low DC offset at the amplifier output, good characteristic tracking over a range of temperatures, and (hopefully) lower distortion. I say hopefully because ideally you want the distortion characteristics of the matched pair to cancel exactly. You are well advised to not assume that matching will actually do this.

Matching is a key to performance in monolithic circuits such as op amps, where it can be conveniently assumed that transistors made next to each other will be very similar. To some extent this is used to lower distortion, but it appears that mainly the intent is to retain constant DC offset and other characteristics over a range of temperatures.

Circuit for Measurement

First we have to decide what we’re interested in, as regular guys who want to build up the best possible circuit without creating an expensive laboratory.

We are going to trust some of the numbers the manufacturer gives, such as the maximum voltage, current, wattage and temperature ratings. These are not difficult to test for, but the average DIYer isn’t going to want to burn up a bunch of parts to get this information. We trust the manufacturer, but usually we divide all his numbers by 2, unless they’re bad numbers, in which case we multiply by 2. This approach aids our success and satisfaction, and improves relations with transistor vendors, all of which are probably doing the best they can.

So what shall we test? The V_{gs} for turn-on is the first we think of - it’s necessary, and is easy to do. Therefore it is popular. It would be nice to see what the gain figure really is under a particular set of circumstances. While we’re at it, it would be nice to see the input capacitance inferred from the high frequency rolloff of the gain, also under varying circumstances. Also we might as well measure the distortion vs. both frequency and amplitude.

We will want to test in both Common Source and Common Drain modes, which comprise the bulk of usage where we care very much about quality and matching. We can perhaps ignore measurements for the usual Common Gate Mode of operation, inferring their values from the others, and noting that as Cascode devices, they contribute little of their own character to the circuit performance.

Figure 4 shows a simplified circuit for measuring some of the practical characteristics of Mosfets with an eye toward their use in audio circuits, and it will allow measurement of the characteristics just identified. The ranges of values of the adjustable resistors in this circuit is from 0 ohms in infinity, and of course this would cover just about any contingency. The DC and AC voltages to be measured would be those at the three pins of the Mosfet and the supply voltage, and from these everything can be calculated. The capacitor must be a low leakage film type.

Measuring V_{gs}

Suppose we simply want to measure the DC value of V_{gs} at a given current. Referencing Figure 4, we set P1 full clockwise. We adjust P3 and the voltage at (V) for the current we want and measure the DC voltage between the Drain and Ground, noting and trimming the voltage

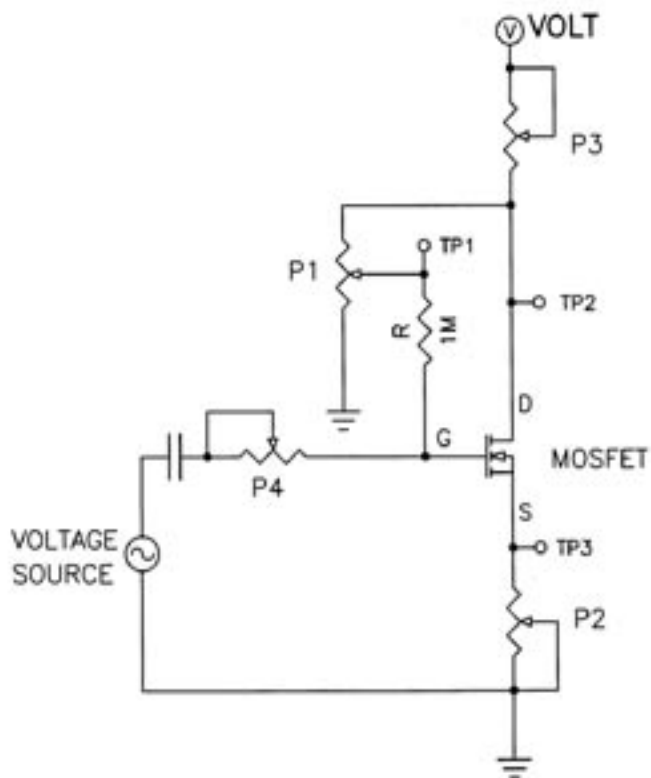


FIG 4 TEST EVERYTHING CIRCUIT

across P3 to insure that the correct amount of current is flowing.

P4 doesn't matter here, as the DC is blocked by the capacitor, but it is always nice to have a few ohms in series with the Gate of any Mosfet to prevent high frequency (parasitic) self-oscillation, which will alter the voltage reading.

Of course if you are simply trying to match Vgs of various devices, you only need to trim P3 and (V) once, and then simply group devices that match within the tolerance you want.

Most of the time we are looking for less than .1 Volt variation in Vgs between devices, and from experience, we see that it is fairly easy to get .01 Volt variation if you have a reasonable population of transistors to work with. In production quantities, we get this all the time. If you only have a few devices, you might have to settle for the .1 Volt matching figure.

The Vgs is temperature dependent, which means that the parts tested should all start out at the same temperature, usually room temperature (I mention this because at Pass Labs we don't heat our inventory area much in the winter, and we have to let the devices sit in the test area to warm

up to room temperature).

Also, as you run the test, you must be aware that you are heating the devices both by running some current and voltage through them, and also by touching them, and the Vgs will alter with temperature. Ideally, you test the devices under conditions identical to the intended use, and this means mounting the devices in thermal contact with a heat sink of the appropriate temperature and allowing for the temperature to settle.

Measuring Transconductance

Using the circuit of Figure 4, you can measure transconductance under arbitrary conditions. In Common Drain mode, if you short P3 and measure across an arbitrary DC and AC value for P2 with an given input signal and supply voltage, you can compare the AC variation of Gate-Source voltage versus the output voltage. The Vgs variation divided by the current through P2 gives the transconductance, so you would be dividing the AC current occurring across P2 (which is the value of the voltage across P2 divided by the AC voltage) and you would be dividing this by the AC voltage which appears across the Gate and test point TP3. TP1 is only used for DC Gate measurements, being connected through 1 Megohm.

In a Common Source setup, we often measure the transconductance using the voltage appearing across a resistive load:

$$\text{Transconductance (Siemens)} = \frac{\text{Output Volts}}{\text{Input volts} / \text{Drain load}}$$

P1 and is adjusted to set up the proper DC bias for the circuit. In Common Source mode, you short P2 and measure across P3, comparing this voltage to the Vgs, once again setting P1 and (V) to the appropriate bias values. The AC current through P3 divided by the AC voltage of Vgs is again the transconductance figure, and once again we can vary P5 to observe the effects of the apparent input capacitance.

Computing the apparent input capacitance is easy enough. Find the frequency where the transconductance drops 3 dB (=0.7 times the low frequency figure) and use the formula

$$C = 1 / (R * F * 2 * \pi)$$

C is in Farads

F is in Hertz

R is the sum of ohms of R5 and the AC source

$\pi = 3.14$.

For example, at low frequencies the transconductance might be 10 at 100 Hz, and if we find it is 7 at 100 KHz with a 1000 ohm AC source impedance, then

$$C = 1 / (1000 * 100,000 * 2 * 3.14) = 1.6 * 10^{-9} \\ = 1.6 \text{ nanoFarads} = 1,600 \text{ pF}$$

Measuring Distortion

Note that all the parameters we measure will depend on the conditions the transistor experiences - all the voltages, currents, temperature, and frequency. You will find that transconductance and capacitance are among these, and these are crucial to audio performance.

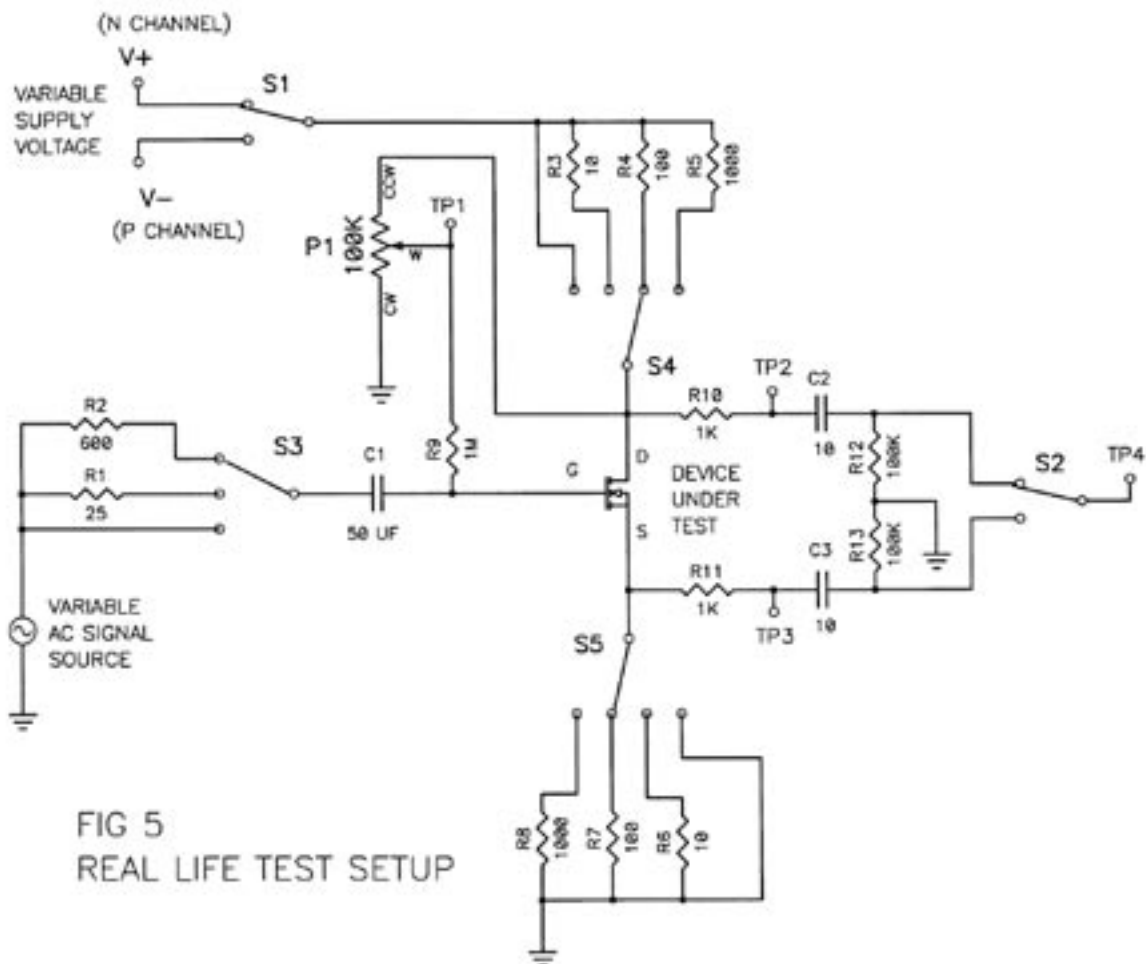
That these figures vary in value gives rise to distortion in the transistor. All distortion can viewed in this manner - variations in gain or loading, which in the case of a Mosfet is the transconductance, and input capacitance.

The input capacitance is a particular problem in power Mosfets where the capacitance can get fairly high and varies with voltage and current.

Measuring distortion is like measuring the transconductance, except that we also look at the output harmonic distortion versus level and frequency. As you would expect, the distortion, which is primarily second harmonic, increases with amplitude and frequency. The amplitude dependent distortion comes from the variation in transconductance versus voltage and current, and the frequency dependent distortion is the result of non-linearity in the input capacitance.

Introducing Figure 5

Figure 5 shows a practical version of the circuit of Figure 4 using switches and power resistors where real current is likely to flow instead of potentiometers. It assumes the use of a variable regulated supply designed to provide the voltages and currents you might find interesting. If you have a dual voltage supply it makes the use of S1 convenient in reversing the supply polarity, otherwise



you have to use a 2 pole switch to reverse both supply terminals.

If you don't have an Audio Precision test rig, you can use an ordinary audio oscillator, wide-band voltmeter and distortion analyzer, but of course it won't be nearly as much fun.

The Drain resistance is varied by S4 from 0 ohms to 1000 ohms, similarly for the Source resistance. Other niceties include some output capacitance and resistance for connection to the input of an Audio Precision (tm) test rig. If using the Audio Precision, you can dispense with S3 and R1 and R2 since the AP has 25 and 600 ohm selectable source resistance.

For Common Source testing, S5 is set to 0 ohms and S2 is set to the Drain of the Mosfet. For Common Drain testing, S4 is set to 0 ohms, and S2 is set to the Source of the Mosfet. P1 is used to provide DC bias to the Gate.

Test points TP2 and TP3 are isolated through 1K resistors to avoid parasitic oscillation of the Mosfet when voltmeter probes are used to measure DC junction voltages.

OK, Let's Measure Some Parts!

Big power Mosfets were tested with 10 ohms on the Drain, medium (TO-220 type) devices were tested with 100 ohms, and small plastic types (TO-92 for example) were tested with 1000 ohms, as befitting their probable use.

IRFP240

First up on the block is the venerable IRFP240, a 200 Volt 20 Amp power transistor of which I personally use lots. The Drain resistance was set at 10 ohms, and the Vgs was measured for three random samples with Vgs of 4.64, 4.52, and 4.66 volts. Two of these were from the same lot code.

Figure 6 shows distortion versus output amplitude of one of the three samples of IRF240, taken at 1 KHZ. There is a considerable similarity between the parts, the ones in the same lot code being virtually indistinguishable from each other.

On this curve the distortion is quite high at the higher amplitudes due to the fact that the Drain is both biased

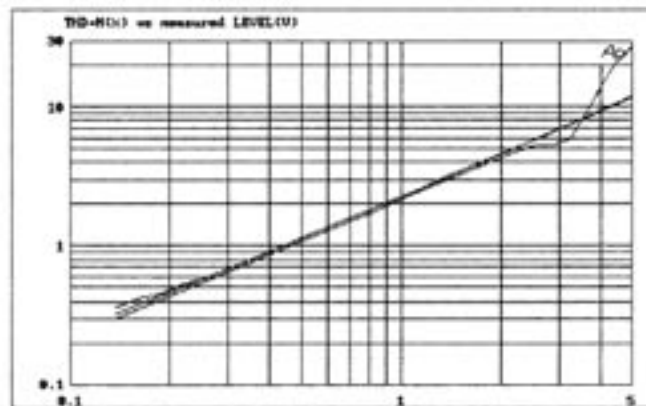


Figure 6 IRFP240 Distortion / Amplitude @ 5 V @ 1 A

at 5 Volts, which is quite low, near Vgs which is about 4.6 volts. As a result, the circuit naturally clips at less than about 3 volts rms (+/-4.2 volts peak). This is a low voltage, atypical of audio use, and so on Figure 7 we have P1 set for 10 volts across the Drain-Source but we show a family with increasing current from an increased power supply voltage. We see clearly that the distortion plummets when offered greater bias current.

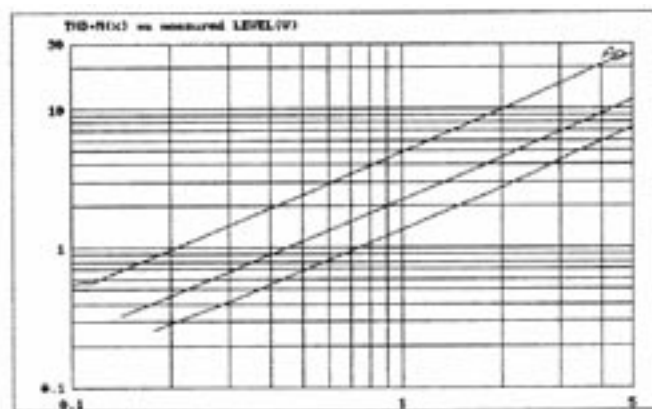


Figure 7 IRFP240 Distortion / Amplitude @ 10 V @ .5, 1.0, 1.5 A

At voltages above a few volts, the distortion figures for these Mosfets tend to converge, meaning that for low frequencies, the Drain-Source voltage does not heavily influence the transconductance. What does have a heavy influence is the amount of DC bias current through the device. Figure 7 clearly shows a rough inverse proportionality between distortion and bias current.

This particular device has a low frequency transconductance of about

$$\text{Transconductance (Siemens)} = \frac{\text{Output Volts}}{\text{Input volts} / \text{Drain load}}$$

$$\text{Transconductance} = 1.39 \text{ Volt} / .050 \text{ Volt} / 10 \text{ ohms} = 2.78$$

Meanwhile, Figure 8 clearly shows that this transconductance will experience a high frequency rolloff determined by the resistance of the driving input coupled with the apparent input capacitance. In Figure 8 we see curves associated with the previous test, but with a constant 1 amp bias, 600 ohm signal source, and with Drain-Source DC bias held at 5 volts, 10 volts, and 15 volts. The capacitance of the input declines with increased D-S voltage, dramatically at lower voltages, and with declining returns as the voltage gets above about 15 volts or so.

The capacitance comes from two main sources, the Gate-Source capacitance, which is high but sees lower voltage, and the Gate-Drain, which is lower in value but often sees higher voltages.

For Figure 8, a 6 KHz rolloff with 600 ohms implies around 44 nanoFarads (nF). This is the same as .044 microFarads or 4400 picoFarads. If you increase the voltage across the Mosfet to 15 volts, this figure is divided by about 5, and now looks more like 8800 pF.

The calculation:

$$C = 1 / (R * F * 6.26)$$

Where C is in Farads R is in ohms (the total impedance of the input source) F is Frequency in Hz

When we compare these results to the International Rectifier data book, we see a quoted figure of about 1500 pf at 10 volts for Gate-Source, and a Gate-Drain of about 300 pf. The voltage gain at the Drain of this circuit multiplies with apparent Gate-Drain capacitance, as this figure is about 28, we expect 300 pf times 28 to be to the contribution from that connection, which would be 8.4 nF. Adding 8.4 nF to 1.5 nF gets us about 10 nF, which is close enough.

The Drain-Source voltage figures into this heavily too. Figure 9 clearly shows the distortion versus frequency improvement to be had when we have a higher voltage supply. Here we see three curves, all 1 amp bias and volt output into 10 ohms. The good looking two curves are at 10 and 15 volts across the device, and the no-so-good-looking curve is taken at 5 volts. If we compare distortion with higher currents through the device, we see minor improvements at high frequencies

What does this say to us? If you want the transconductance to be linear, you run a high bias current. If you want more bandwidth out of the Mosfet, give it

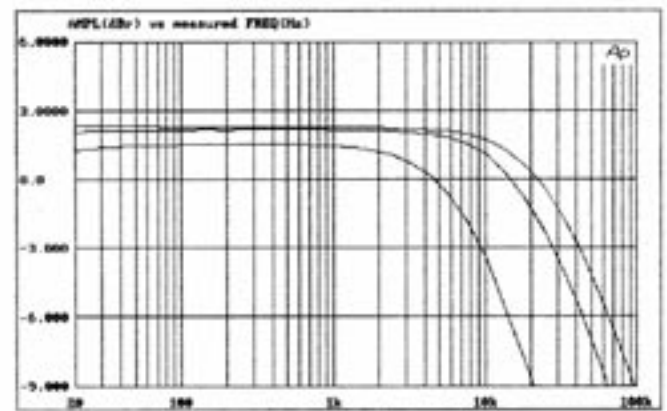


Figure 8 IRFP240 Transconductance / Frequency @ 1 A @ 5, 10, 15 V

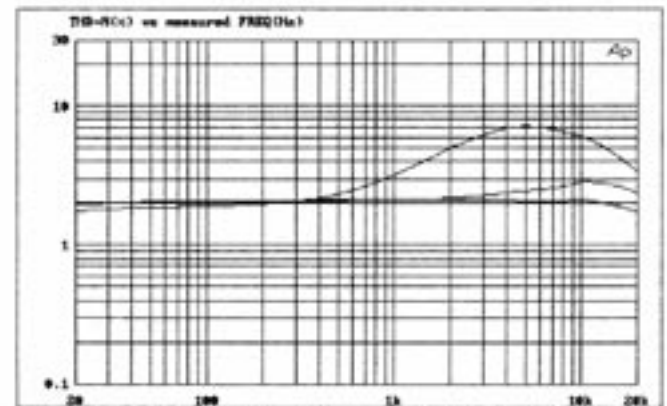


Figure 9 IRFP240 Distortion / Frequency @ 1 Amp @ 5, 10, 15 V

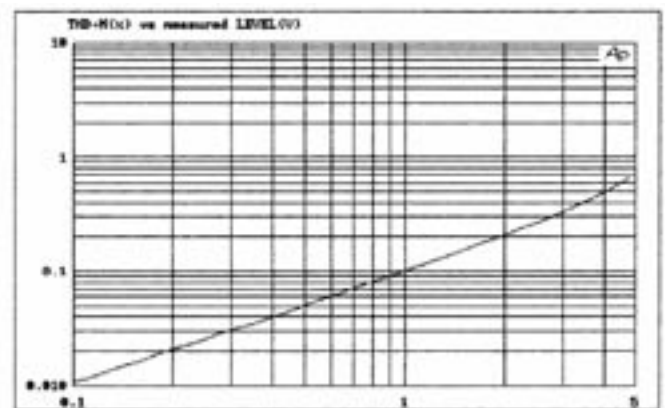


Figure 10 IRFP240 Distortion / Amplitude (Com Drain) @ 10 V @ 1 A more voltage (and a lower impedance source). If you want both, run the device hot.

You might get the impression from these curves that an IRFP240 is a high distortion device, but in fact we are not necessarily showing it in its best light. Figure 10 shows the distortion vs amplitude for the part in Common Drain (follower mode), Figure 11 shows the frequency response of that output, and Figure 12 shows the distortion curve vs frequency, the latter two curves taken at 1 volt input and a 10 ohm load. These are good figures. Want to see bad? I could show you some Bipolar or Tube curves worse than these.

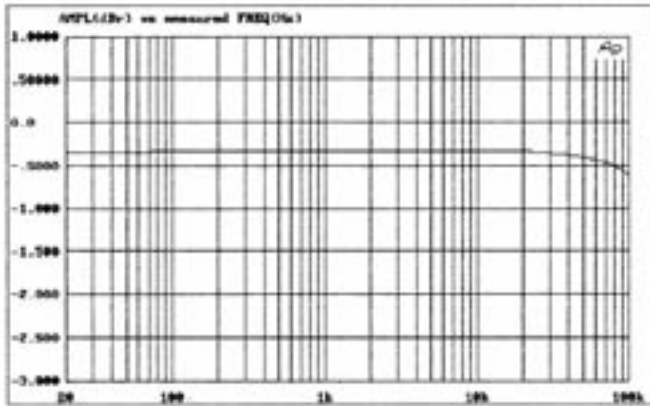


Figure 11 IRFP240 Amplitude / Frequency (Com Drain) @ 10 V @ 1 A

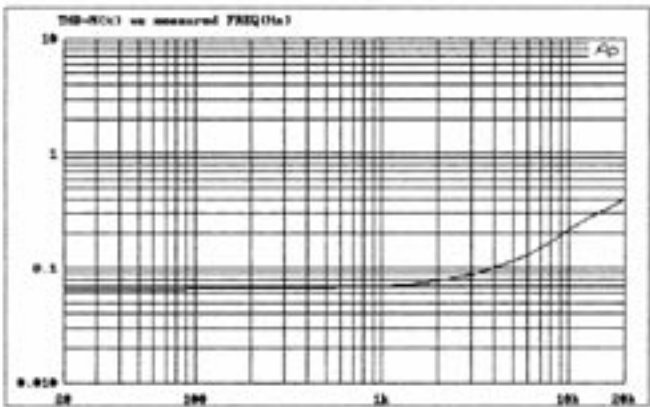


Figure 12 IRFP240 Distortion / Frequency (Com Drain) @ 10 V @ 1 A

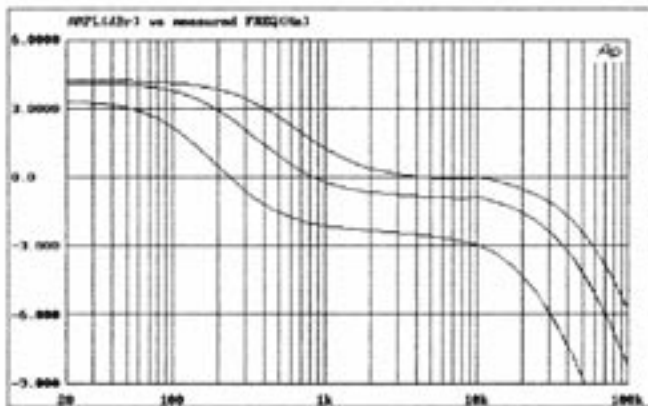


Figure 13 IRFP9240 Amplitude / Frequency @ 5, 10, 15 V @ 1 A

The IRFP9240

As a concept this part is supposed to provide an inverse polarity complement to the IRFP240, and it does this more or less. The voltage and current ratings are similar, the transconductance is somewhat less, but otherwise it looks fine.

Until you run a frequency response curve on it where Figure 13 show the surprising result. The

transconductance dips down as you approach the midrange. Then it shelves off flat for a bit, and proceeds on its ordinary decline at high frequencies.

Where is this from? Who knows? The effect does decline with higher voltages as seen in Fig 13 where we have 5, 10 and 15 volts across the Drain. Higher current does not reduce it, as seen in Figure 14, taken at .5 and 1 amp currents. How bad is it? I've seen worse. Oddly, the Harris version of the same part does not show this.

Does this mean the P channel IR parts are to be avoided for linear use? No, I don't think so - I've been building commercial amplifiers with the emphasis on N channel parts for many years, but I still find the need for some P channel components, and I have not had many difficulties with this. You need to keep the characteristic in mind and work around it, and you also need to remember that these curves represent some worst case test scenarios. Having had the opportunity to compare IR versus Harris in real amplifiers, we have seen advantages and disadvantages both ways, and so we don't get too excited about it.

If you want to make some lemonade out of this particular lemon, use it to design an amplifier with a little more control to the bottom end of an amplifier and less feedback over the mid and high frequencies.

IRF610

If the IRFP240 is the popular "poppa bear" of the Mosfets, then the IRF610 is the "momma bear". Housed in a TO-220 package, it does medium power duty at 200 Volts, 3 Amps, and 40 watts. It was tested with a Drain resistance of 100 ohms.

Figure 15 shows a family of curves of distortion versus amplitude for a 10 volt Drain voltage and with current at .05 amps, .1 amp, and .15 amps. Of course the lowest distortion comes from the highest bias current.

Figure 16 shows a family of curves of distortion versus amplitude with the Drain biased at 5 volts, and also 10 and 15 volts. Not a lot of difference, as with the larger IRFP240.

Figure 17 shows us that the bandwidth with a 600 ohm source gives us a 150 KHz rolloff, with a 1 volt output and a voltage gain of about 30 (transconductance = .3) and by our previous example calculation implies about a 1.7 nF input capacitance.

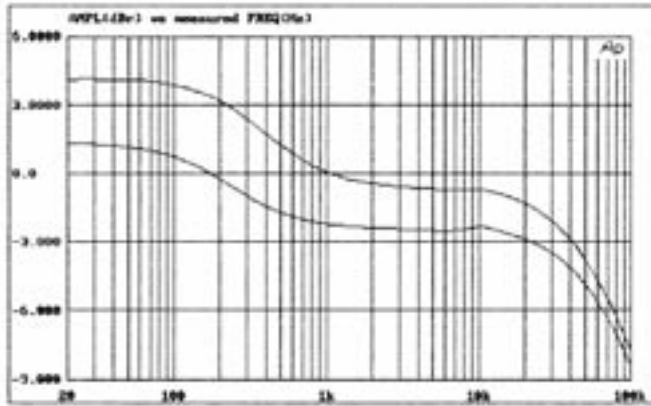


Figure 14 IRFP9240 Amplitude / Frequency @ .5, 1.0 A @ 10 V

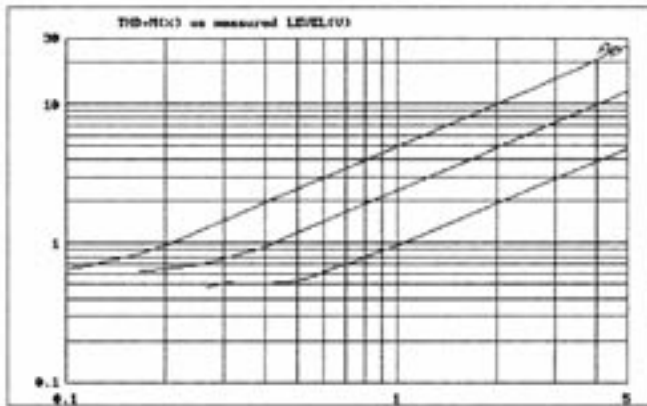


Figure 15 IRF610 Distortion / Amplitude @ .05, .1, .15 A @ 10 V

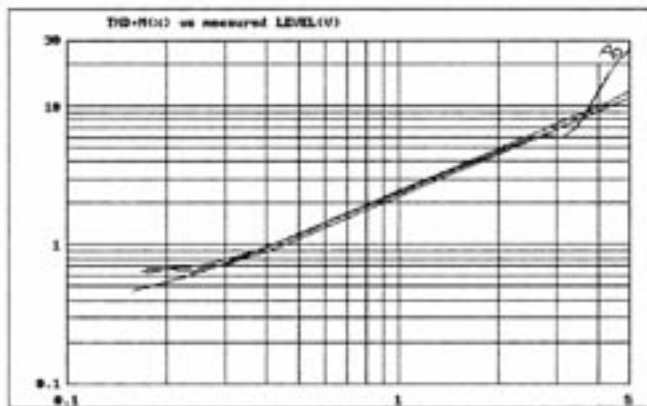


Figure 16 IRF610 Distortion / Amplitude @ 5, 10, 15 V @ .1 A

Comparing this to the rated 140 pF Gate-Source capacitance, and 30 times the rated 9 pF Drain to Source capacitance, we surmise that perhaps this sample offers more input capacitance than the “typical” specification.

Figure 18 shows the distortion versus frequency for this part at 10 Volts, 100 ohms, and 1 volt out. The distortion is the same across the audio band.

The IRF9610 exhibited the same sorts of variation vs

frequency as seen in the IRFP9240. This was the IR part, and I did not have a Harris example on hand to test.

ZVN3310

Now we come to a nice small signal-type Mosfet, the Zetex ZVN3310. We will be loading the Drain with 1000 ohms. Figure 19 shows the distortion vs. output for two 10 mA current bias and 20 mA bias. Gee, the distortion goes down with more bias!

The transconductance is about .03 or so, and the bandwidth makes it out to about 300 KHz or so, which surprises me as a bit low, probably an artifact of our set setup. The distortion is flat across the band (yawn). Nice part, and the complement ZVP3310 looks about the same.

Conclusion

So we’ve seen how we can do some tests on Mosfets, and that their performance is limited and varies from part to part. This variation is a lot bigger than we see when we measure passive parts such as resistors and capacitors, and deserves much more attention.

Commercial linear amplifier manufacturers can’t take the time to carefully measure each component - they depend on high gain and feedback to smooth out the bumps in the performance of individual parts. Only the high-end designer or hobbyist might put the time into individually testing active devices.

If you are only building one amplifier you can set up the circuit so as to substitute parts in and out and evaluate the performance of the permutations. Whether by measurements or listening, if you know what you want when you get it, this approach will work for you.

If you are building one amplifier and don’t want to take the infinite-number-of-monkeys-with-typewriters approach, you measure a population of parts and pick what appear to be the best ones. This practical procedure works well, but misses the occasional symbiotic relationship that can occur between two particular parts.

For example, the notion that matched parts is the best approach doesn’t always hold up. We have had success swapping parts in and out of production amplifiers at random until we got the best performance, then soldering those in permanently. Doing this can often get you much less noise and distortion, if you judge with a distortion analyzer. Alternatively, it can give you better subjective

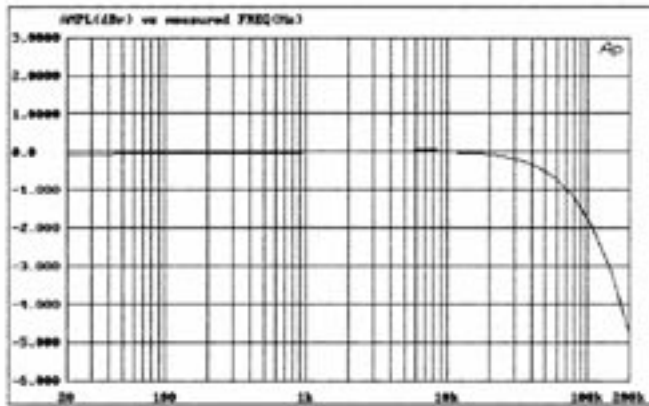


Figure 17 IRF610 Amplitude / Frequency @ 10 V, @ .1 A

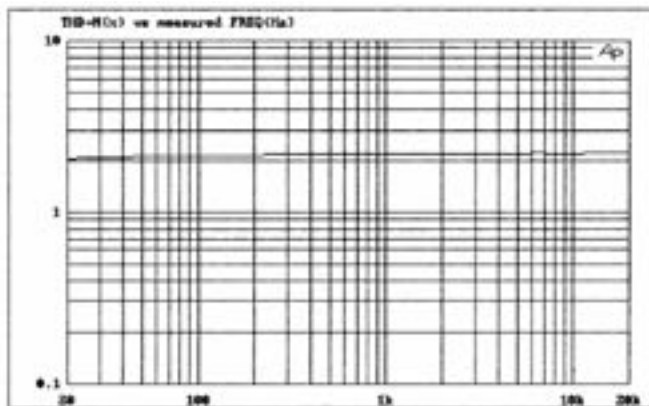


Figure 18 IRF610 Distortion / Frequency @ 10 V, @ .1 A

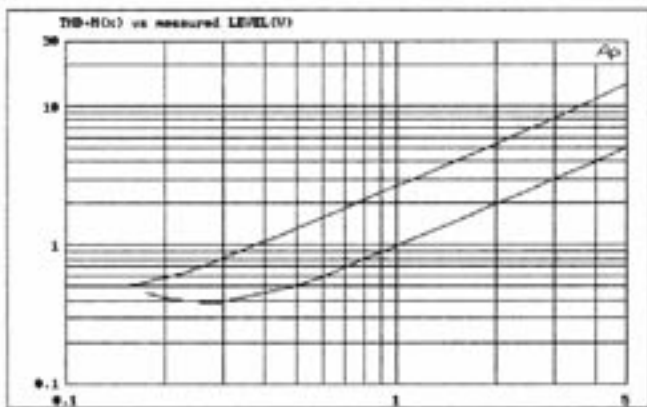


Figure 19 ZVN3310 Distortion / Amplitude @ 5, 20 V @ 10 mA

sound, if listening is your preference (and you have lots of time!).

As a manufacturer, I don't design with building only one amplifier in mind, so I like to proceed as follows: Get a population of parts for the amplifier and measure each, cataloging the results. Then swap the parts in and out of the prototype, two channels at a time and measure and listen. And continue to listen until someone complains about time-to-market.

Once you have figured out what combination (or sets of combinations) of characteristics you want, it's not that tough to select them for production. It takes time and energy, but saves time at the test bench and your customers get a more consistent product - one that sounds more like the prototype on which you lavished all that attention.

What about the parts that don't make the cut as signal bearing devices? They make good active constant voltage and current regulators, or you can sell them to your competitors.

Is this approach applicable only to Mosfets? Of course not. It works with any part, but in particular has great value with active gain devices of any sort - those parts that suffer the most variation and are most important to the sound.

Once last time: The active devices with which we build amplifiers have more influence over the sound than the quality of the passive parts, and also have much wider variations between pieces. The emphasis in the marketplace on the differences between resistors, capacitors, and wire is misguided if we ignore the transistors or tubes. If you want a better amplifier, measuring and selecting the individual gain devices is a good place to start.