

Now for something *Completely* Different:

First Watt model F3

Power JFET Amplifier



PART 1: Introduction and Philosophy (You can skip this part)

There are two basic elements to an amplifier design – the parts you use and what you do with them. Of the parts, the active gain devices are the most important critical – they contribute most of the distortion, and their characteristics heavily influence the rest of the circuit design.

The better the parts, the simpler the circuit can be. The more subtle the circuit design, the more you get out of the parts, and the better the sound.

Simplicity not only reduces the number of parts that the sound has to go through, it requires design that maximizes the linearity of each gain stage and minimizes the feedback.

For the last twelve years I have been exploring power amplifier designs with only one gain stage (the Zen series www.passdiy.com) in contrast to commercial designs using as many as nine gain stages. The simple amplifiers often don't measure up as well in demanding applications, but when the speaker is easy to drive and the music isn't too loud, a simple amplifier often sounds better.

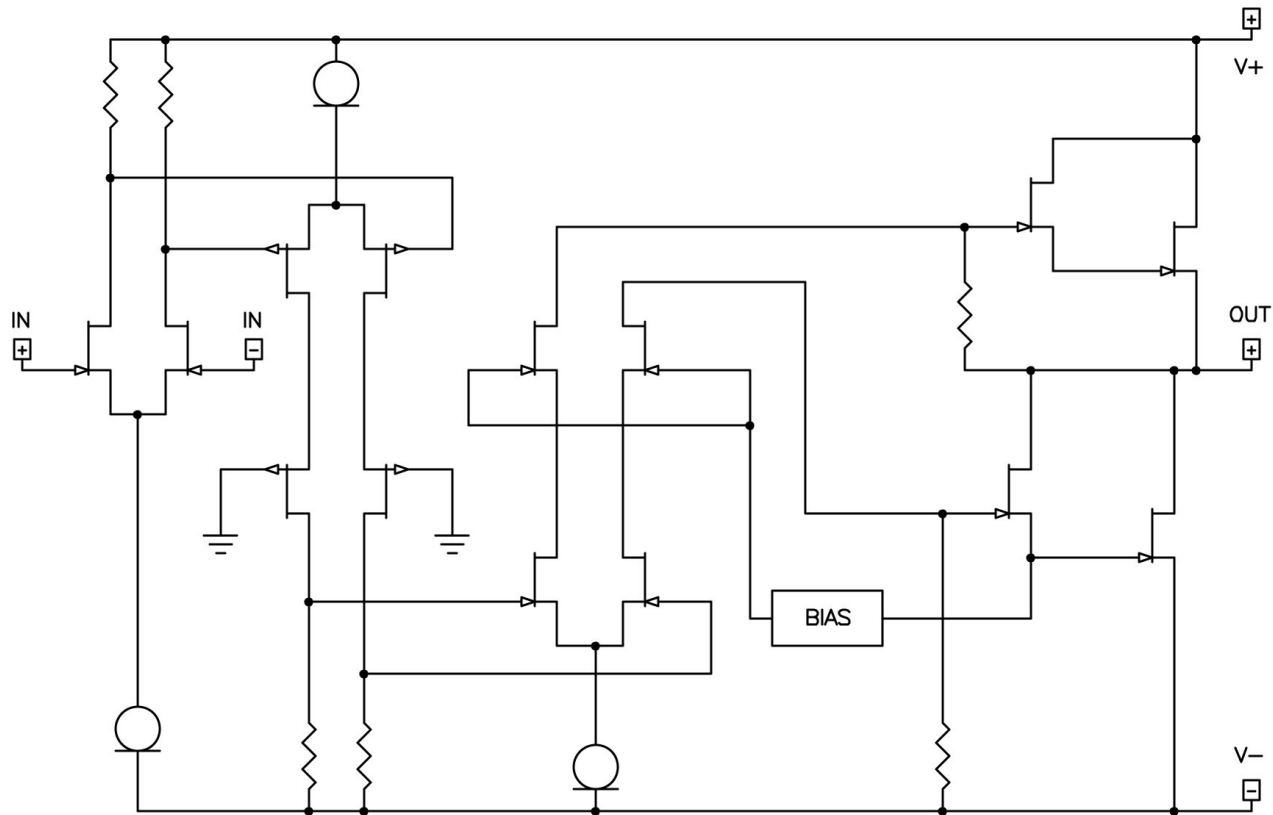
To get these single stage amplifiers to work, I've been using power MOSFETs as the gain devices. These were the only devices which had the characteristics to make a practical single-stage power amplifier – high input impedance, high voltage and current capacity, and high gain. The Zen amplifiers were all Class A designs, both single-ended and push pull, and they all delivered about 10 watts or so. Some used feedback, some didn't, and they all measured between .05% and .5% harmonic distortion at 1 watt.

Power MOSFETs were chosen by default. You can't get a practical single stage power amplifier from a tube – the gain is too low. A bipolar transistor has too low an input impedance. And there were no power JFETs on the market.

JFETs, or Junction Field Effect Transistors, are routinely used in the input stages of the finest solid-state amplifiers and preamplifiers, where they give very high input impedance, high linearity, and very low noise. JFETs are often extolled in promotional literature for their “tube-like” qualities.

To my knowledge, power JFETs as such have not previously made it to the market. In the 1970's, Sony and Yamaha offered a series of JFET power amplifiers using their own semiconductors, but discontinued them after a few years. I have been told authoritatively that product reliability was an issue. Nevertheless, the amplifiers remain highly regarded for their sonic performance.

Here is a simplified schematic of the five stage Yamaha B1, which used low power cascoded JFETs in the three front end gain stages and also a fourth output drive stage which then drove Power JFET output transistors in a Class AB mode.



SIMPLIFIED YAMAHA B1 JFET AMPLIFIER

Since then, JFETs have only been available as low current, low power signal devices. MOSFETs have become the dominant field effect power devices mostly because they make great switching devices in power supplies and such. It is possible to make power JFETs which are better in linear amplifiers than the current MOSFET offerings, but probably the market has been judged too small.

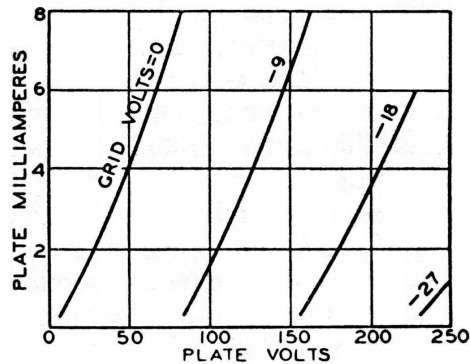
In recent years, advances have been made in vertical JFET design which makes them more competitive in switching applications, and as a result power JFETs have been re-introduced after a thirty-year absence. Earlier this year I published the "Zen Variations #8 – the Power JFET Amplifier" and now First Watt is introducing the model F3, at this time the world's only commercially available amplifier using power JFETs.

Why power JFET's you ask? Don't we have enough transistors already? We do have lots of choices in devices, but a power JFET brings some particular advantages to the table that we don't get elsewhere.

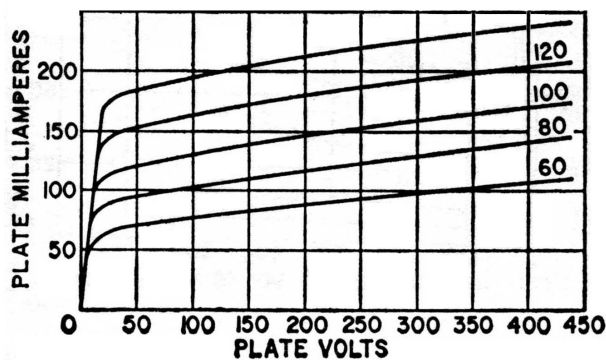
First off, for comparable devices at a given bias current, we see that the power JFET has much less distortion. The original F3 circuit was designed with a MOSFET, and comparing "apples to apples", the power JFET operated with one-fifth the distortion of the MOSFET.

That's only the beginning. The JFET has much less distortion operated as if it were a MOSFET, but it's not a MOSFET, and it has characteristics which allow for even better performance.

When we look at the anode (or tube plate) voltage curves for devices we see what I would call the "triode character" and the "pentode character".



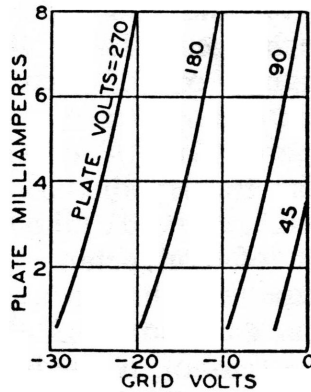
Above is an example of the triode character. On a triode, for a given grid voltage, as the plate voltage rises the current goes up in an exponential fashion.



Above is the pentode character. In contrast to the triode, the current tends to level out more with increasing voltage in what looks to be a roughly logarithmic fashion. It has a "convex" shape as compared to the triode's "concave" shape. A distortion free linear device such as a resistor would have a straight line.

Since no gain device does a perfect job of approximating a resistor, various techniques have been developed over the years to make them more linear.

Another curve common to field-effect devices is the transfer curve of the device operated at a constant voltage across the device, as seen below. We note that like the triode curve, its shape is exponential in character.



Triode designers linearize the tube circuit by operating the voltage/current load line so as to get some cancellation between competing voltage (plate curve) and current (transfer curve) distortions. This can be done with either single-ended or push-pull circuits.

The way it works is like this: For a fixed Grid-Cathode voltage, the current rises exponentially with Plate-Cathode voltage. For a given Plate-Cathode voltage, the current rises exponentially with Grid voltage. Both these curves look similar on paper. When you use the tube as an amplifier, these two curves oppose each other – while the gain is rising at higher voltage, it is also declining because of the reduced current, and these two effects can be made to cancel, resulting in more linear performance.

Designers will choose the voltage and current operating conditions to exploit a “load line” which is the region the tube traverses over its operating cycle. By carefully positioning the load line, tube distortion can be dramatically reduced. (Unfortunately, this works best for resistive loads, and not as well if the load is reactive or has the wrong impedance value)

That’s all very nice for triode circuits, but gain devices with pentode-type curves, which include MOSFETs as well as pentodes, cannot take as much advantage of this technique. While they have the exponential transfer character, their anode voltage curve does not cancel in the same manner. They must use different approaches, most commonly feedback.

But as you look at the curves for these power JFETs you can see a narrow region below 5 volts and 10 amps where the anode characteristic looks like a triode, so that a load line can be constructed which further linearizes the device.

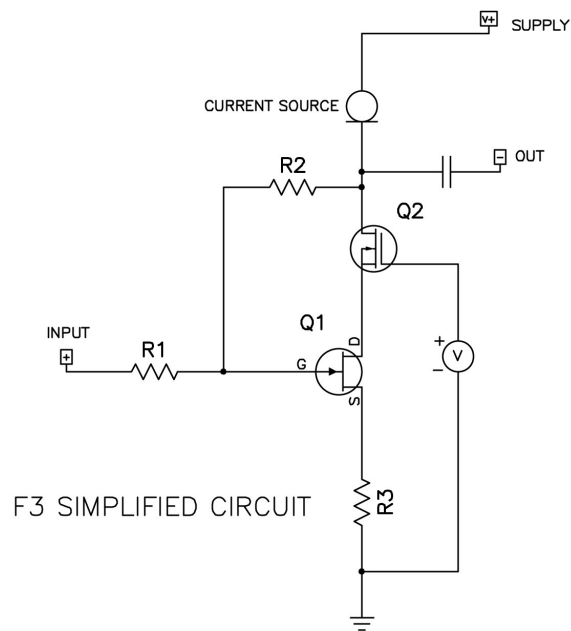
If we have a gain device that behaves a bit like a triode, then it is natural to try it out in a popular triode amplifier topology. For many aficionados that topology would be single-ended Class A operation. 300B's, 211's and their cousins operated single-ended and coupled to an output transformer have been held by many as the low power musical standard. Single-Ended Class A tube amplifiers are not very powerful, and their measurements are nothing to write home about, but there is no denying that they have strong musical appeal to a sizable segment of the audiophile population.

Getting the most linear performance from these power JFETs relies on a topology known as cascode operation. The JFET is operated with a Common Gate partner device which contributes so little of its own character to the output that it doesn't rate as a gain stage per se, but it shields the actual gain device from the output voltage. Cascoding makes the voltage across the JFET constant, and so gain variation due to fluctuations of Drain-Source voltage (the music) vanishes. Cascoding also dramatically reduces the need to charge and discharge the input capacitance of the JFET.

Cascoding also allows a relatively low power, low voltage power JFET to operate in a high voltage, high wattage environment with little dissipation. The cascoding device acts as an umbrella, taking the heat while leaving the JFET completely controlling the current through the circuit.

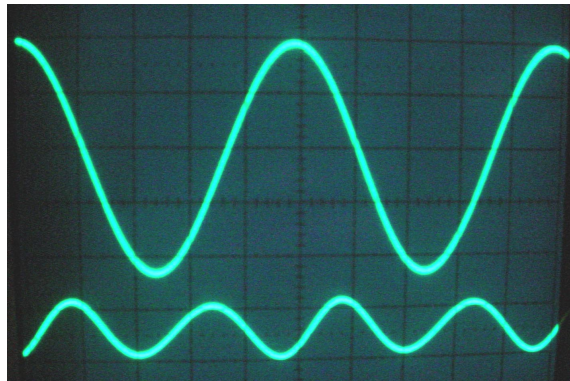
Freezing the voltage across the JFET lowers the distortion by itself, but does not give us the most optimal load line for the device. For absolutely lowest possible distortion, the JFET must see some voltage fluctuation across its Drain and Source pins. For this purpose I developed a "modulated cascode" topology (you heard it here first), which imposes a slight voltage variation across the JFET as a function of the current through the device.

The advantage of this circuit is that the load line truly becomes a function of the output current, not the output voltage. This works better than the classic triode approach because it accounts for reactive loads or loads which are not the correct resistance. The F3 is set up so that the load line of the JFET can be adjusted with two degrees of freedom, tweaking the circuit to the individual character of the JFET. With this adjustment, the F3 gives about 0.01% distortion at 1 watt. This is a remarkable achievement for a single-stage power amplifier - the original Zen amplifier had sixty times that figure at 0.6%



Here is the simplified schematic of the F3. It bears a superficial resemblance to the Zen Variations #8 circuit, but it is not the same, as evidenced by the higher performance of the F3.

Being a single-ended Class A circuit, its characteristic is “second harmonic”, that is to say the distortion curve is dominated by a second harmonic as seen below.



Second Harmonic Distortion

As you can see from the curves and specifications in the back, this is a good low distortion amplifier in the ordinary context of solid-state amplifiers, and is a phenomenally good single-stage amplifier.

While much of the explanation here has used tubes as examples, I am not suggesting that I wish to emulate tube amplifiers as such. I want to give a basis for understanding the advantages of these new devices and the types of circuits that elicit the best from them. At the same time, you will hear some similarities, partly because there are similarities to the measured performance, and partly because both types of design have a similar philosophy and minimalist discipline.

I am mindful of what happened when MOSFETs first arrived, when mediocre designers simply threw them into the same old bipolar circuits that they had copied from the RCA manual and the marketing departments trumpeted how tube-like they were. They weren't, and it has taken years for the reputation of MOSFETs to recover and for designers to put them into circuits where they are most appropriate. Power JFETs are remarkable new devices that offer some specific advantages, and I fully expect them to take their place in circuits which uniquely address their qualities.



I note that it was just about this date 30 years ago when Rene Besne and I sat down to listen to the final prototype of the Threshold 800A (shown above), which was my first commercial offering.

Times flies when you're having fun.

If you have questions, comments or problems, you can email me at

nelson@passlabs.com or www.firstwatt.com

Those of you eager to build your own instead of buying an F3 can get information on the Zen Variations #9 at the Pass Labs DIY site www.passdiy.com

PART 2: Setup (Probably You Should Read This Part)

The initial setup of the amplifier is very straight-forward. Place the amplifier in a well-ventilated location, as it draws nearly 200 watts during operation and requires as much opportunity to cool itself as possible. You should be able to put your hands on the heat sink during operation. If you can't do this for 5 seconds or so, they need more ventilation.

On the front panel there are two blue LED lights, one for each channel, indicating regulated power to the channel. If the light is on, the power supply regulator for that channel is delivering voltage. On the rear panel you will find pairs of RCA inputs, speaker outputs, a fuse holder, an AC power receptacle, and on/off switch and a label.

The label will indicate a serial number and also what AC line voltage the amplifier is set for. If the voltage is 120 VAC, then the fuse value will be a 3AG slow blow fuse rated at 2.5 amps. If the voltage is 240 VAC, then the fuse will be rated at 1.25 amps. Do not substitute a larger value fuse. Contact First Watt if you have any questions.

I'm assuming that you know how to attach the speaker cables to the 5 way output connectors provided. I recommend that you make all the connections with the amplifier power switch in the OFF position, but you will not damage the amplifier circuit by accidentally shorting the output or overdriving the input - my concern is more for the safety of any fragile loudspeaker driver you might be using.

Note that the (+) red terminals of the outputs are a ground potential, and that the (-) black terminals are live. This is important to remember if you decide to bridge the channels or if you are using the output of the amplifier to drive an active subwoofer's input.

With everything connected up and the source equipment powered up first, you can proceed to turn on the power switch to the amplifier. Turn-on and turn-off thumps and noise are small in this amplifier, and should not present any hazard to delicate drivers. It takes about 1 minute for the regulators to come up to full voltage, so don't expect full output power for that time.

At this point you should be able to listen to music. This amplifier has less gain than most, but at 15 watts rating, it should not need it. If you need to turn the gain up on your preamp, then do so. If you can't get enough gain, then you are probably using either the wrong speaker or the wrong amplifier. Talk to your dealer if this is the case.

The power supply of the amplifier is isolated from the chassis and AC earth ground by a thermistor which connects the circuit ground to the chassis and earth ground. This helps to prevent ground loops, but the thermistor stands by to conduct AC line voltage to ground until the fuse blows in case of transformer or other such failure.

The input impedance is the IHF standard of 10 Kohms, and the input capacitance is very low, so you should find it easy to drive with tube equipment if you like. It would be a pitiful source that would not be able to deliver 240 micro-amps required to clip this amplifier. The amplifier is largely indifferent to the source impedance of your preamp, so a high source impedance is not a problem.

The F3 has enough damping factor (8) to work well with loudspeakers that mate well with tube amplifiers in general, and it delivers good performance into 4 and 16 ohms also – see the distortion curves at the back of this manual. It is designed around relatively high efficiency speakers and it particularly shines with those that have 90 dB/watt sensitivity or greater, but you can hook it up to anything you like, as long as you adjust your expectations as to how loud it will play.

The amplifier requires about 1 hour of operation to reach normal operating temperature, and this warm-up time is appropriate for the most critical listening, but is not otherwise an issue. The amplifier's final adjustments were been made after an hour, but the performance difference between 5 minutes and 60 minutes is marginal.

I do not personally see a reason to run the amplifier all the time, but you can do that if you want to. The power supply capacitors are likely to last about 15 years or so, and while they will slowly dry out just sitting there, they will have a shorter life span with the amplifier running constantly. Also, at 200 watts it makes economic sense to shut the amplifier off if you aren't planning on using it for the rest of the day.

Again, the heat sinks on this amplifier run fairly hot, and you want to make sure that they get adequate ventilation. They will run at around 25 degrees C. above the ambient temperature, which puts them around 50 degrees in the average listening room. At this temperature you should be able to put your hand on them for about 5 to 10 seconds or so.

If you have any questions, contact First Watt. I answer all questions, even if the answer is no.

www.Firstwatt.com

nelson@passlabs.com

PART 3: (Absolutely Must Read This Part)

Now the following is for your protection –

Do not defeat the AC line Earth ground connection on the amplifier power cord. It provides an extra barrier to prevent potential shock hazard.

Do not replace the fuse with a type other than specified.

Do not operate the amplifier outside in the weather, or in and around water or anything resembling water. If you spill a drink in the amplifier or if your dog/cat/child urinates on it, turn it off immediately, unplug it, and do not operate it until cleaned by a qualified technician.

If something gets loose or rattles around inside or smells funny, or if you can't touch the heat sinks for 5 seconds or so, then turn it off, unplug it from the wall, and contact First Watt.

There are no user serviceable parts inside. Do not open the amplifier, and if you do anyway, don't operate it with the cover off. There are hazardous voltages inside. If you need to change the operating AC voltage, contact First Watt.

If you have a problem, contact First Watt. We are much happier helping you solve problems so that we can be certain that it's done properly. If you are far away and don't want to ship the product for repair, we will assist your technician with information and parts.

Contact: www.Firstwatt.com nelson@passlabs.com

PART 4: Technical Poop (Optional Bathroom Reading)

Summary of the nominal specifications:

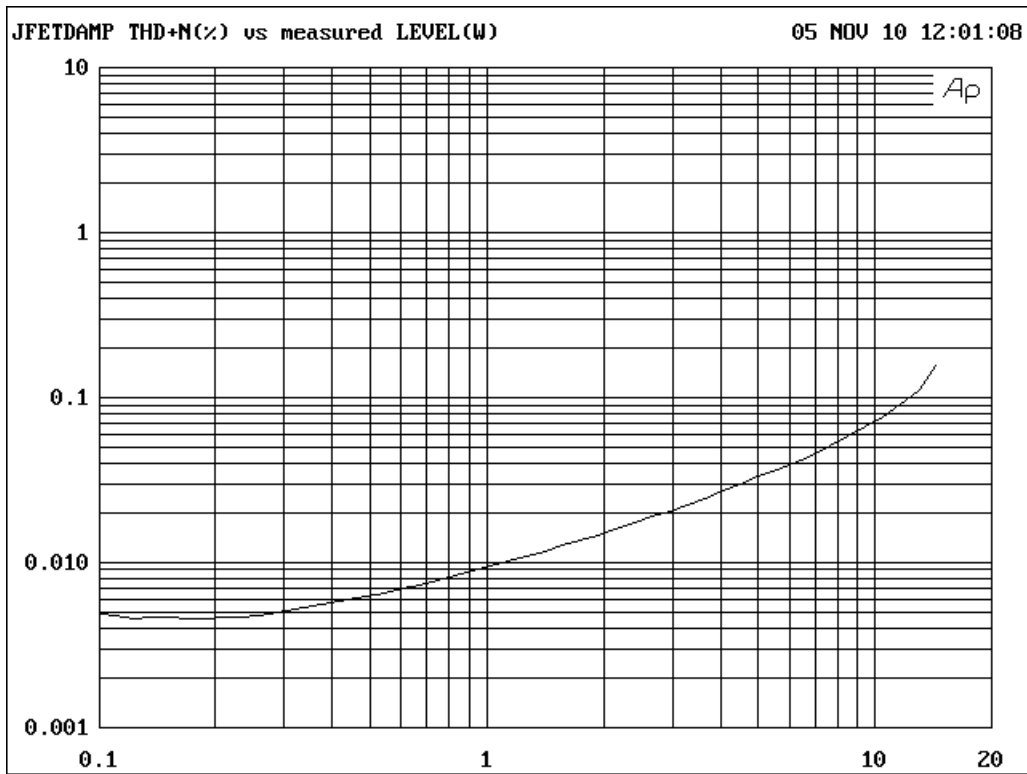
Measured at 120 V AC with a 25 ohm source and an 8 ohm load:

Distortion @ 1 watt	.01% @ 1 KHz, typical .005%
Input Impedance	10 Kohm
Input Sensitivity	650 mV for 1 watt, 8 ohms
Damping Factor	6
Output power 8 ohms	15 watts @ 0.2% THD, 1KHz
Output Power 16 ohms	10 watts @ 0.1% THD, 1 KHz
Output Power 4 ohms	10 watts @ 1% THD, 1 KHz
Gain	12.75 dB (+/- 0.25 dB)
Maximum unclipped output	+/-13 volts, +/- 2.5 amps
Frequency response	- 3 dB @ 1.5 Hz, 75 KHz
Noise	100 uV unweighted, 20-20 KHz
Power consumption	200 watts
Fuse	3AG slow blow type, 2.5 Amp for 120VAC 1.25 Amp for 240 VAC

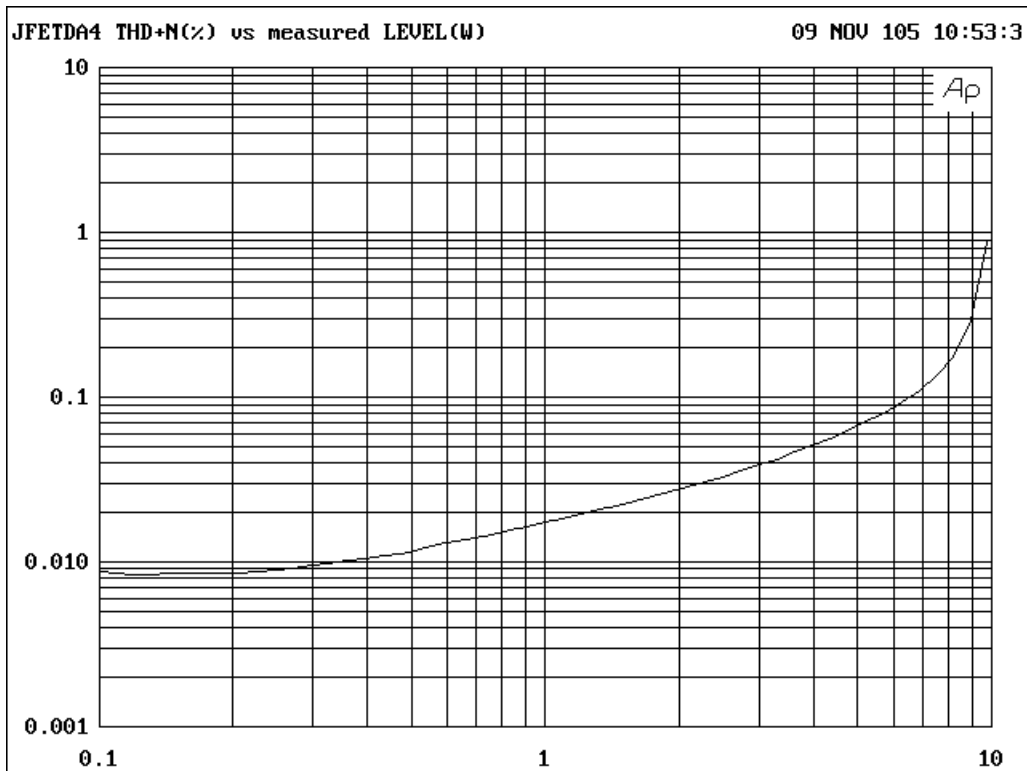
Warranty: Parts and labor for 3 years, not covering shipping costs or consequential damages.

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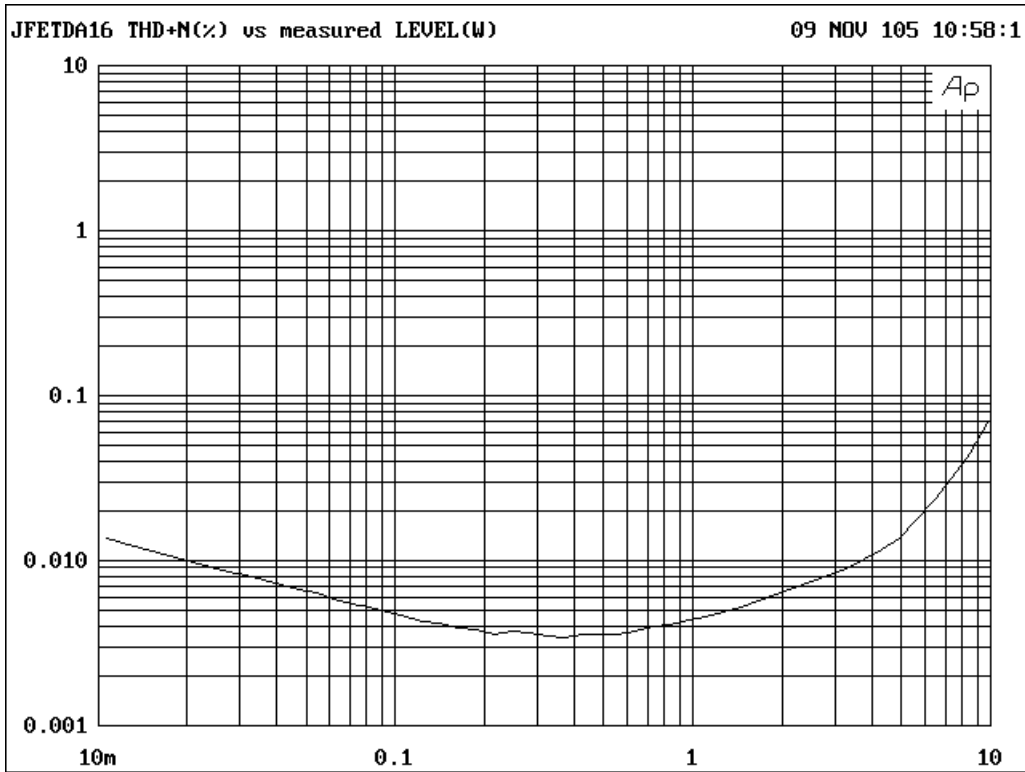
General Amplifier Inc.
PO BOX 7607
RENO NV 89510-7607



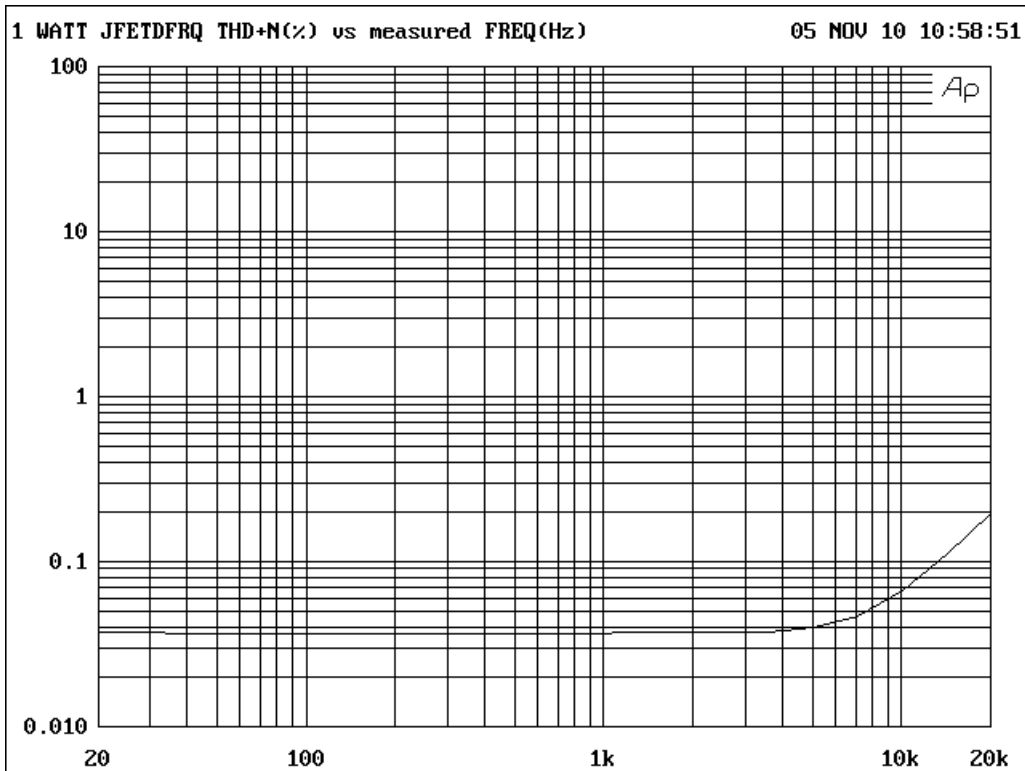
DISTORTION VS WATTS @ 8 OHMS, 1KHZ



DISTORTION VS WATTS @ 4 OHMS, 1KHZ



DISTORTION VS WATTS @ 16 OHMS, 1KHZ



DISTORTION VS FREQUENCY @ 8 OHMS, 1 WATT