The Beast with a Thousand JFETs.

(actually Two Thousand Three Hundred and Fifty-Two)

By Nelson Pass

Roger and Me

When I was young, in the halcyon age of the late 50's and early 60's, I spent my Saturdays at the one of the two local theaters watching “B” science fiction and horror movies. I particularly liked the Edgar Allan Poe epics starring Vincent Price, as well as titles like “Attack of the Crab Monsters”, “War of the Satellites”, and the ever popular “Little Shop of Horrors”.

You could safely say that these movies deeply influenced my outlook on life, but it was not until I was in my late 20's that someone gave me a book about Roger Corman that I realized who was responsible for most of these films. Additional years of Corman films and subsequent reading revealed more about Roger Corman.

It is said that Roger Corman has never lost money on any of his hundreds of movies. Apparently he initially lost money on the “Intruder”, which seems to have been William Shatner's debut, probably because it was a morality tale on race relations, but I am informed that it has since become profitable video release. Having purchased a copy, I like to think that I tipped it into profitability.

It has been said that if you work in Hollywood you run into Roger twice in your career – once your way up and later on your way down. Certainly it is true that the list of people who worked with Roger early in their careers forms a Who's Who of the film industry, including Jack Nicholson, Ron Howard, Robert Di Niro, Martin Scorsese, Francis Ford Coppola, Sylvester Stallone, Peter Fonda, Peter Bogdanovich, James Cameron, Quentin Tarantino, William Shatner, Lloyd Bridges, Beverly Garland, Charles Bronson, Robert Vaughn, Barbara Steele - the list goes on and on.

Roger Corman had something of a formula for his earlier efforts:

First, you pick a name that will capture the imagination of the movie going public.

Second, you make up a lurid movie poster that features a scantily clad woman being threatened by whatever creature is featured in the title. The actual monster need not be visible.

Third, you take the name and poster around to all the distributors and get them to buy into it.

And if they do...

Fourth, you film the movie on a tiny budget in a few weeks.

My kind of guy!

One day in 1999 my wife Jill and I were talking about “who would you pick to have dinner with if you could”, and my choice was Roger Corman. Without my knowledge, Jill got my attorney to write a nice letter to his movie company explaining that I was not a stalker, rather a devout fan warped by a lifetime's exposure to his work, and the ultimate result was an invitation to lunch. I flew to Hollywood and we met at The Grill. For an hour and a half I ate a salad and basked in the presence of Roger Corman. We mostly talked about movies and our kids and even amplifiers. At the end he autographed a photo for me and let me buy the lunch. It was one of the best 1.5 hours I have spent.

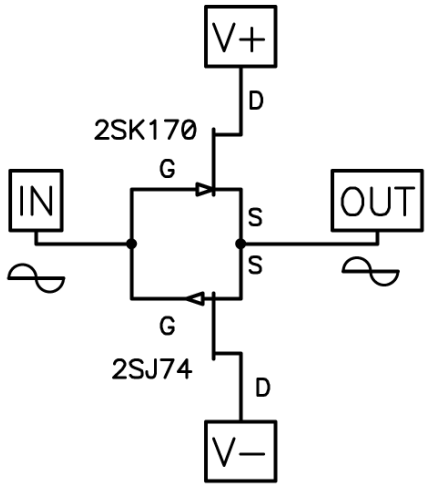
Recently Roger was awarded an Oscar for his lifetime of work.

Now I told you that story so that I can tell you this story:

The Two Jfets

For several decades Toshiba made probably the finest complementary Jfets that you could buy - the 2SK170 and 2SJ74. They are very low noise parts, quiet enough to serve as amplification for the lowest output moving coil cartridges. They self-bias at very convenient current levels and they are one of the lowest distortion transistors every made.

Being complementary types, they make excellent follower (“buffer”) circuits for audio applications. Here is an example of such a circuit:



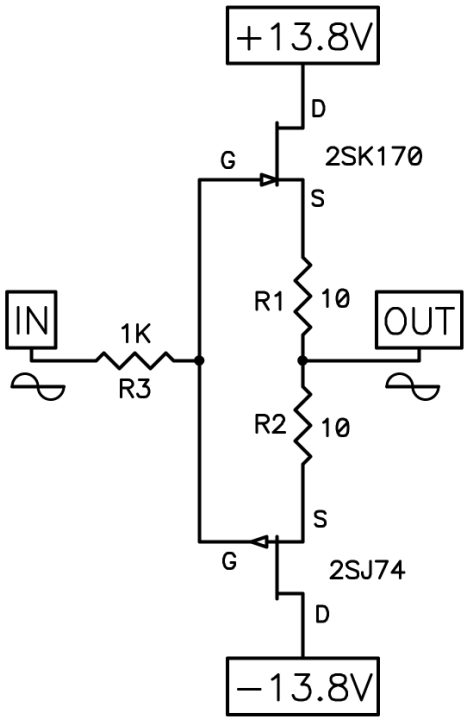
COMPLEMENTARY JFET FOLLOWER

An “N” channel Jfet (2SK170) and a “P” channel Jfet (2SJ74) are joined at the Source and Gate pins, and the Drains are attached to V+ and V- power supply voltages. The relationship between the Gate to Source voltages of the devices determines the current flow through the Jfet, and in this case insures that the Source Pins “follow” the input voltage faithfully. The input impedance of the Gate pins is extremely high, but the output impedance is quite low, around 20 ohms or so, and so the circuit is a “buffer”. It's voltage gain is unity, and the amplication is purely that of current.

This stage is operated push-pull Class A and has a bias (idle) current of the Idss figure of the Jfets. The Idss is the current which flows when the Gate and Source of the transistor are at the same voltage. For 2SJ74 and 2SK170 devices, the Idss range is broken down into 3 groups: GR is 2.6 to 6.5 mA, BL is 6 to 12 mA, and V is 10 to 20 mA.

These devices have a limited voltage rating, 25 volts for the P channel 2SJ74 and 40 volts for the N channel 2SK170, and this creates a practical limitation for the rail voltages in this push pull circuit of about 12 volts or so. They also have a limited dissipation rating in free air, 0.40 watts.

There are some practical additions to the circuit above in the form of three resistors:



BASIC BEAST CELL

R1 and R2 inserted in series with the Source pins of the Jfets helps to set the current at a slightly lower desirable value than Idss and provides a convenient place to measure the current and adjust the DC offset when the Idss values of the N and P devices are not perfectly matched.

Jfets are sufficiently fast that you can encounter problems with parasitic oscillation unless you take some steps to “damp out” potential RF energy. Resistor R3 accomplishes this.

You will perhaps notice that I have specified actual supply rail voltages – those of two car batteries. You might want to power this up with standard lead-acid cell car batteries (you wouldn't be the first one to do so) and also you can find cheap commercial supplies with high current ratings at this voltage.

So we ask the musical question, as a power amplifier how many watts will this circuit deliver into an 8 ohm loudspeaker?

Well, with an 10 mA bias current, it will run Class A to about 20 mA peak, and considering the power formula:

W = R * I^2 which becomes W = 8 * .02 * .02

then the peak output into 8 ohms is 0.0032 watts, or about 1.6 milliWatts rms.

Clearly we're going to have to do something dramatic to make this into a real power amplifier, and this is where Roger Corman comes in. One of his movies was "***The Beast With a Million Eyes*** *, in which the monster's powers depended on having a large vision.

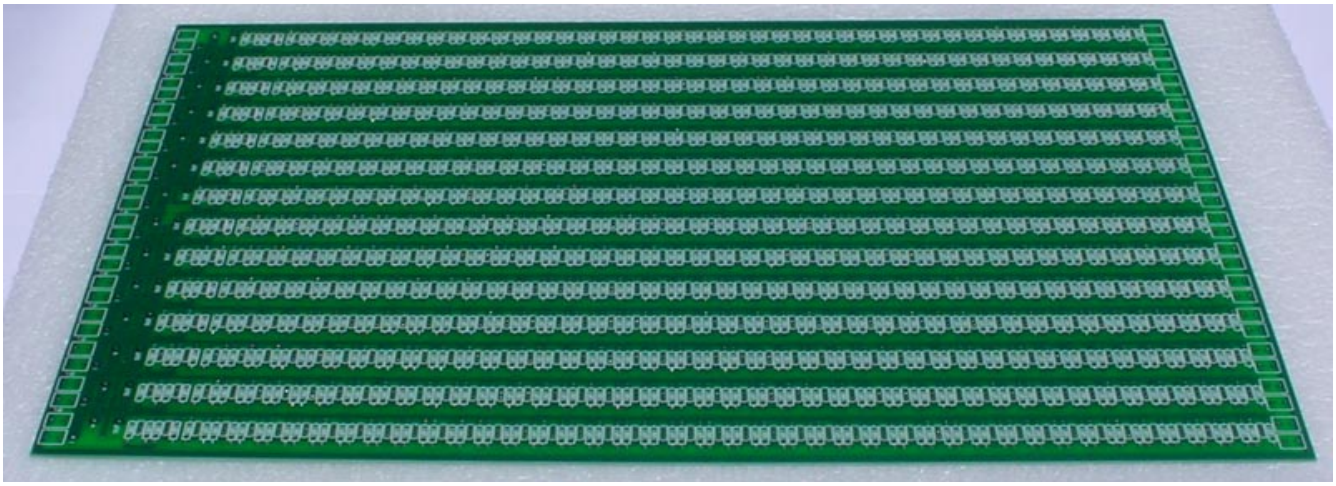
We can arrange these circuits in parallel for more current, and we can run them balanced in series to achieve twice as much output voltage. We can expect more than 25 watts of voltage into 8 ohms and 50 watts into 4 ohms running balanced stages with the 13.8 volt supplies, so then it becomes a matter of how many of the circuits (cells) in parallel will be needed.

50 watts rms into 4 ohms requires a 5 amp peak. If you parallel devices to multiply your 0.02A individual cell current to get that, you need 5/.02 or 250 of them. Of course there are two such devices per cell, and the system is run with two parallel sets of cells, so we end up needing about 1,000 Jfets per channel.

Roger Made Me Do It...

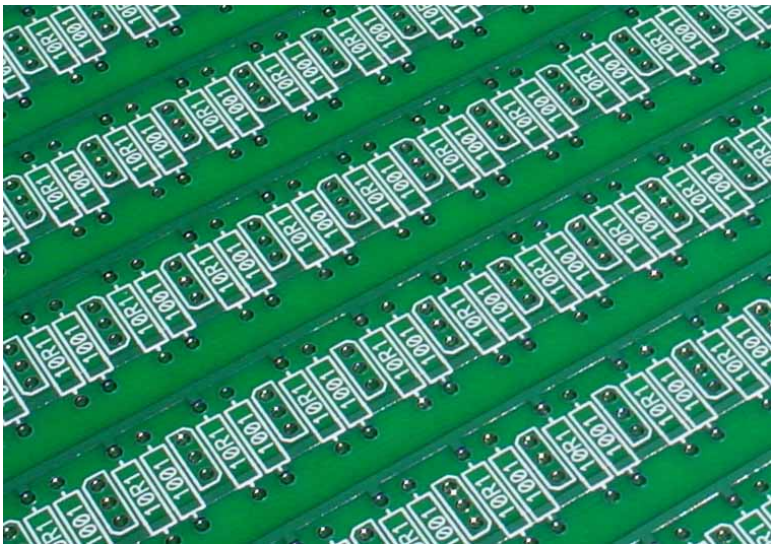
When I went to lay out the circuit artwork for this, I found that I had space to do a 14 X 21 array of cells for each half of a channel, and so the actual figure turned out to be 1176 Jfets per channel, but what's a little overkill among friends?

Here is a picture of that half-channel circuit board:



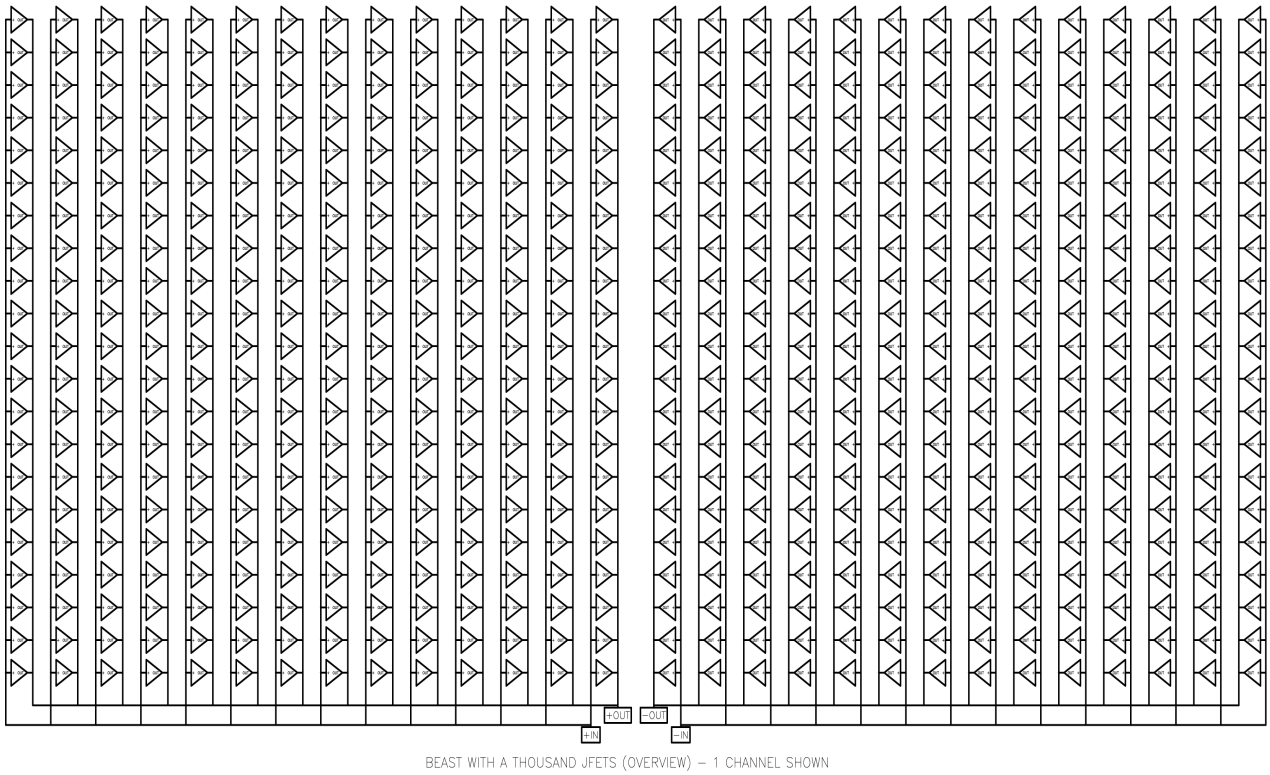
** Corman was co-producer of this film, but apparently became the uncredited director when union difficulties arose.*

And here's what the board looks like a little closer up:



Yes, it's *massively parallel*.

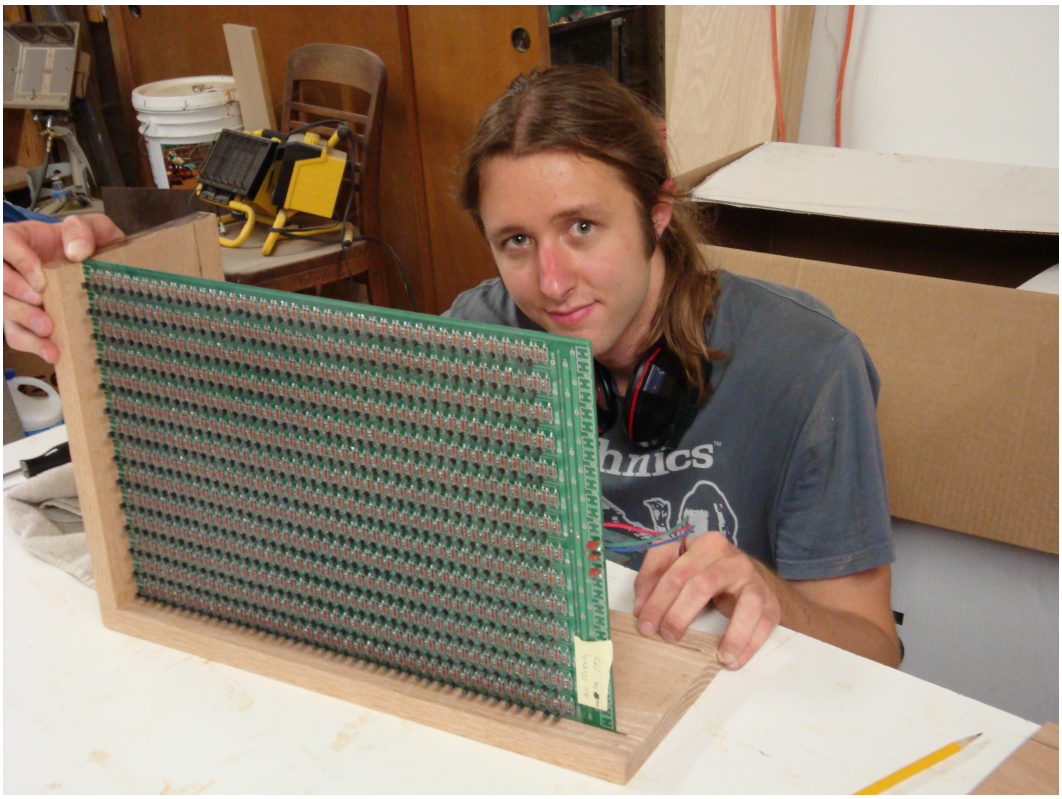
A pair of these amplifiers requires 2352 of these Toshiba Jfets. As they are discontinued and therefore precious, it is doubly crazy to devote this quantity of these parts. Here is an overview of the arrangement of the cells:



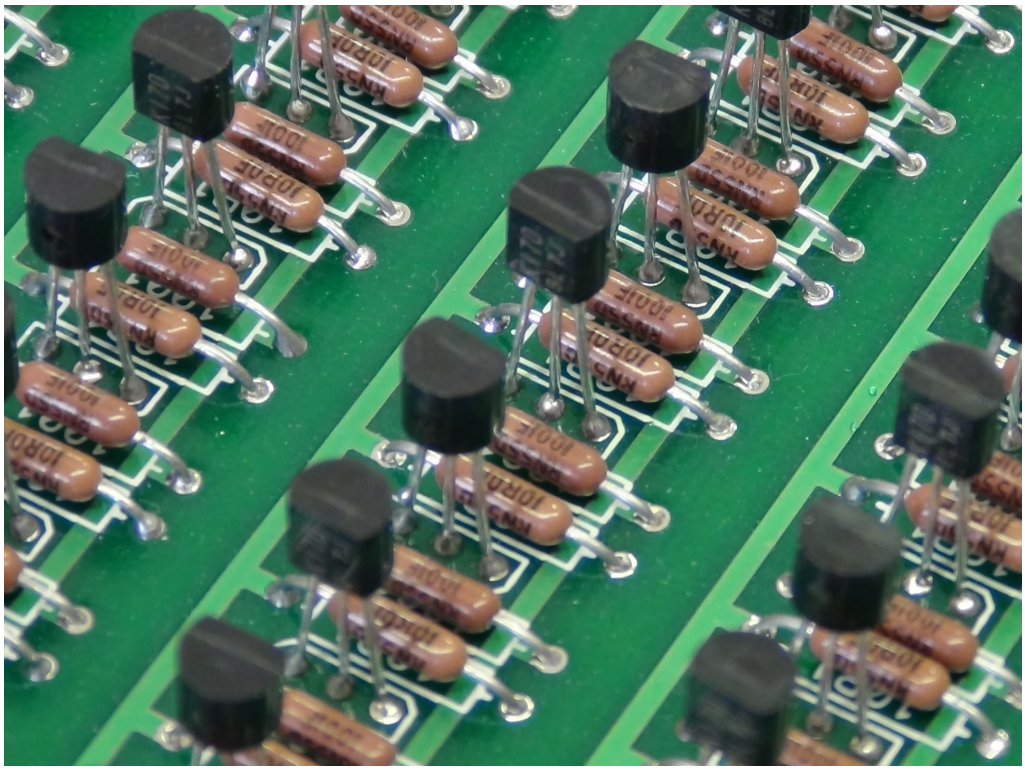
BEAST WITH A THOUSAND JFETS (OVERVIEW) – 1 CHANNEL SHOWN

I apologize that the details are somewhat tiny. Muuuuu Hahahahahaaaaa.....

Here is a picture of the patient and multi-talented Roth Wiedrick assembling the channels:



Roth tested the Idss of each Jfet and soldered them into the boards:



Roth also made some nice enclosures out of solid red oak.

I told you he was multi-talented...

What you can't see is that there are two boards to each box, one on each side. The power supplies are external, and the input is via balanced XLR connectors.

What you might be able to make out is that the front and rear edges of the circuit boards contain large numbers of capacitors in parallel to ensure that the power supply impedance remains low at all frequencies. This is a very fast circuit, and it is not very tolerant of inductance in the supply (which is remote).

The bias current of each channel comes out around 5 amps, and we expect the amplifier to leave Class A around 6 amps output (peak), which is more than enough for Class A operation at full power into 4 ohm loads, and about 70 watt peaks into 2 ohms. We get a little more Class A region than usual due to the square law character of the devices, the trans-conductance of the Jfets being somewhat dominant over the 10 ohm Source resistors.

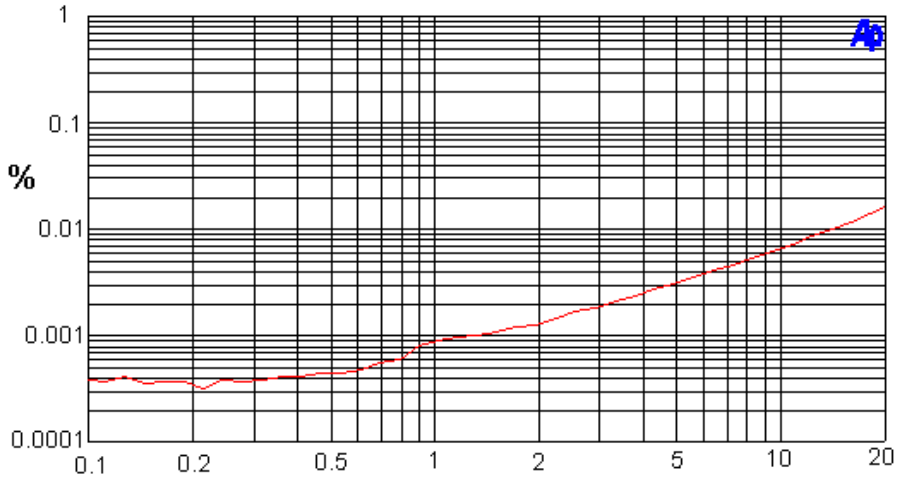
The amplifiers do dissipate about 140 watts per channel, and you can clearly feel the heat radiating off of the sides. The individual devices are running at about 130 milliwatts, well below their rating, and I have not encountered any difficulty with reliability since firing them up nearly two years ago.

Measured Performance

The ordinary objective performance of the amplifier is quite good.

The bandwidth extends from DC to about 1 megaHertz, and the character of the performance is consistent very much beyond the audio band. The output impedance is about 0.2 ohms so the damping factor is about 40. The noise is at the bottom of the resolution of my test setup.

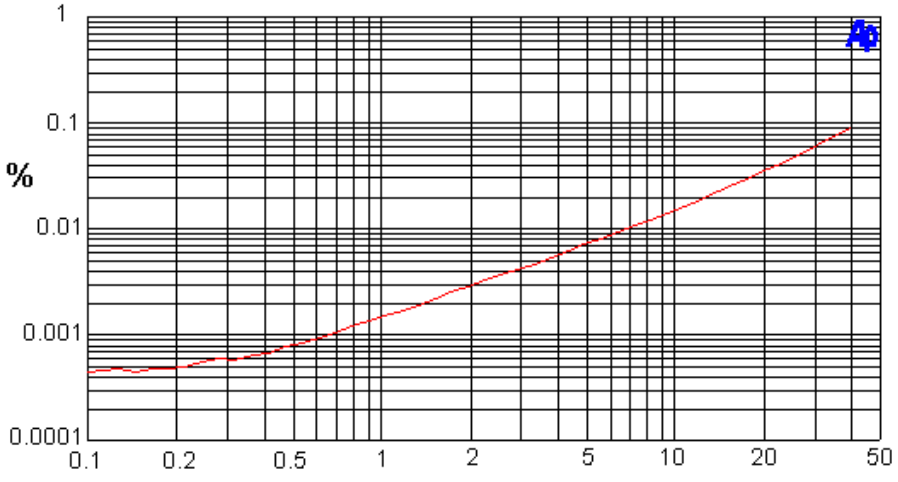
Here are some curves, starting with power into 8 ohms:



THD VS OUTPUT POWER @ 8 OHMS

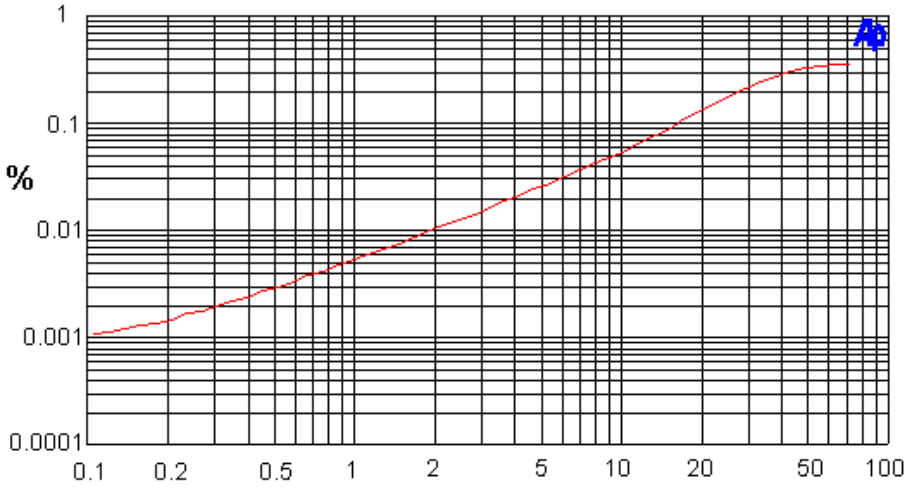
Note that the amplifier was driven by an Audio Precision System 1, whose maximum output is a little under 14 volts rms. Routinely the amplifier can do a few volts more, but that's just icing on the cake.

Here is the distortion into 4 ohms:



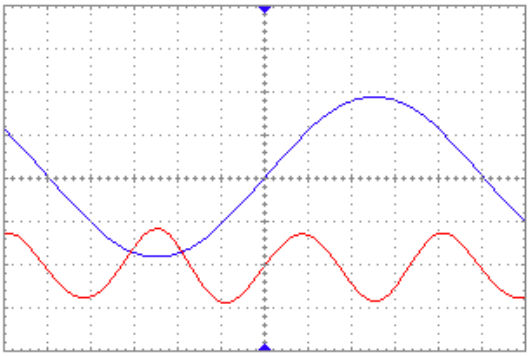
THD VS OUTPUT POWER @ 4 OHMS

Finally, here is the distortion into 2 ohms. At this point you can see the amplifier starting to poop out at about 70 watts into 2 ohms, which is about 8 amp peaks, more than expected.

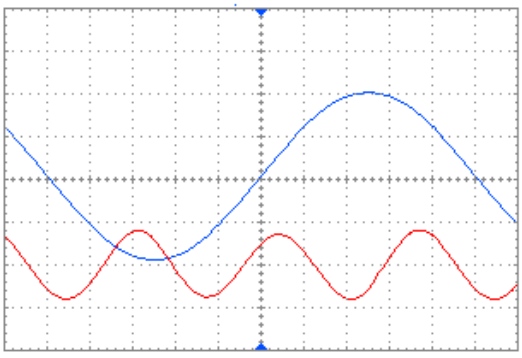


THD VS OUTPUT POWER @ 2 OHMS

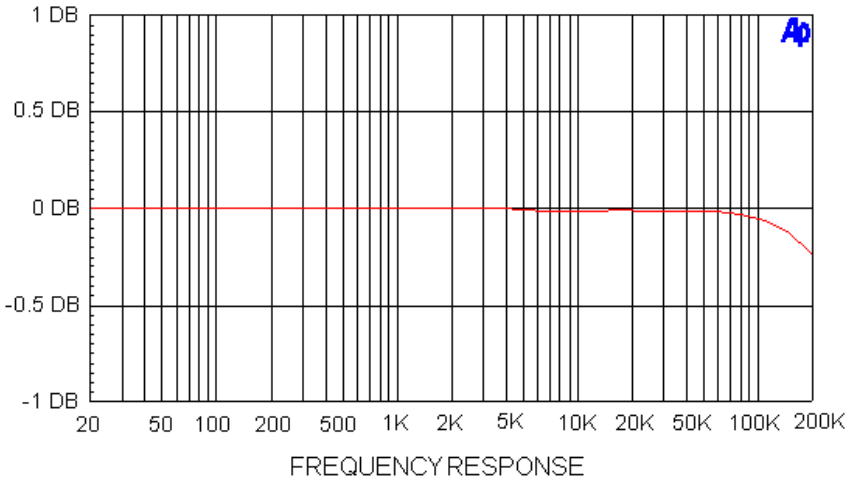
Here is what the waveform distortion looks like. Due to the strong symmetry of the circuit, it is the expected third harmonic at a little more than .002%, and you will note the absence of visible higher harmonic orders:


DISTORTION @ 4 WATT 1KHZ 8 OHM

That same test at 20 Khz with the same amount of distortion.


DISTORTION @ 4 WATTS 20 KHZ 8 OHMS

Here is the frequency response driven by a low impedance source.



A word about input capacitance. The Jfet pairs here have an input capacitance of about 38 pF, and as you start paralleling them up, you multiply this value, Fortunately, running balanced results in halving the ultimate values, but in the end the two 294 pair in series works out to about 5.5 nF capacitance as an input, or about 5 times the old IHF standard.

If you wish to get the performance presented, a 50 ohm source will get you about 600 Khz bandwidth, but a 600 ohm source will roll off at 50 Khz. I run about 100 or 200 ohm sources, so I don't have much problem with this, however I did consider the possibility that this would not be acceptable to someone (*isn't that always the case?*).

So I provisioned the circuit board so that first cell of each rank of 21 Jfet pairs can be set up as a driver to the remaining 20 simply by strapping that section accordingly. This way the input capacitance is reduce by a factor of about 20, down to around 250 pF, and allowing for a 1 megahertz bandwith with a 600 ohm balanced source.

The same people who might complain about the capacitance might also complain about the added complexity of drivers. Well, you can't have it all. I have listened to and measured it both ways, and I find it comes out about the same.

The Sublime and the Ridiculous

Besides the fun of the raw craziness of such an amplifier, what's the point? The point is to build a simple amplifier with exquisitely good raw performance and see what it sounds like.

Will it open up new vistas of audio experience, polishing out the last smudges on our windows of perception?

Or will it un-involving and clinical like so many ultra-low distortion efforts we have seen in the past?

I'm inclined toward the former.

I've listened to the amplifier over the last couple years with XP10, XP20, and XP30 balanced preamps and also directly driven by a Wadia 16. The loudspeakers have included SR-1's, SR-2's, Lowther PM6a and Feastrex D9nf (both open baffle), Zu Essence, Tannoy HPD 15's, and of course my JBL L300's. Source material has been Vinyl, CD, and 24 bit.

From the measurements and looking at the waveforms I had some preconceived notions about what to expect, but I was a little surprised. Usually amplifiers with so little distortion are a little dry and shall we say, "*accurate*", and at the same time, my experience is that typically pure third harmonic character tends to be more dynamic sounding than a second or mixed harmonic tonality.

This amplifier is a little less dynamic than most third harmonic pieces, possibly from the lack of feedback, but it is not dry. If it were a wine, I think of it as maybe a light auslese riesling, as contrasted with the fat red cabernets that I like to receive from DIYers (*hint, hint*).

It's very slightly sweet, which is pleasantly surprising, and it has great clarity, letting a lot of depth and detail through without any hint of aggressive qualities. Where the sweetness comes from, I don't know.

Mostly though, the amplifier is not there. At night, without an "on" light, it's really not there.

Conclusion

Roger Corman turns 87 on April 5. I and many others will take a moment to appreciate his contributions to our culture. Here is an older photo displaying his dedication to his work.

What of the future?

I think I need an amplifier based on this poster: