Now For Something Completely Different:

the F7 Power Amplifier

Introduction - Short Story Long:

Conceived in 2007, the F5 was a push-pull Class A amplifier employing eight semiconductors and 23 resistors to achieve 25 watts output with good specifications and good sound. You can read about it in detail in both the owner's manual and DIY construction article, both posted at www.firstwatt.com

The F5 received good reviews, sold well and received plenty of attention from the DIY audio community (as of this writing, the F5 thread on www.diyaudio.com is cresting 3 million views). Like other First Watt amplifiers, it was a limited release, and was discontinued after 100 pieces were built.

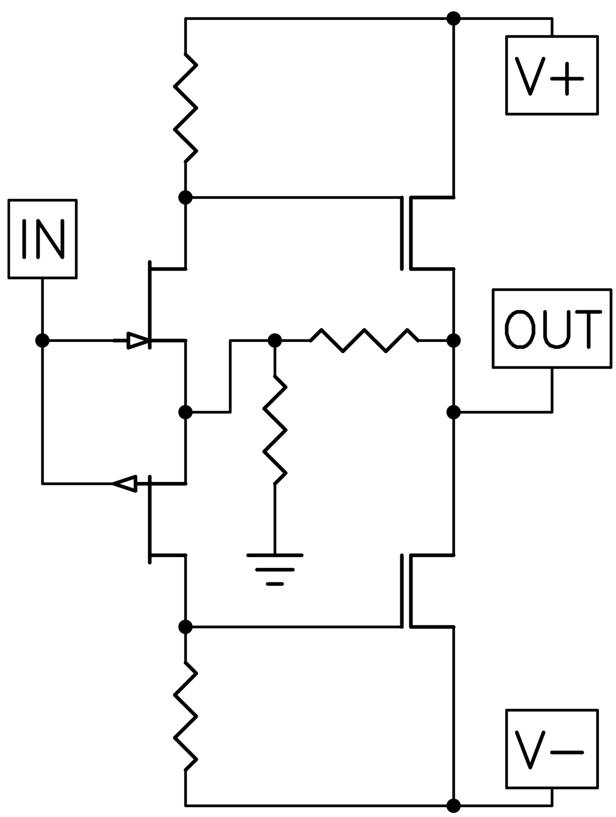
Subsequently there was a more powerful version released to the DIYers, the F5 Turbo, which offered more power and numerous options for experimentation.

The F5 was noted for detail and neutrality, the result of simple Class A operation, wide bandwidth, and a generous amount of negative feedback. With some material and equipment, the sound was exquisite, but the amplifier also tended to highlight the faults of recordings and the rest of the system. A poorly engineered record, a second-rate DAC or peaky loudspeakers and the amplifier was merciless.

Since then I have spent time mostly exploring other kinds of design approaches to amplifiers, but I always meant to come back to the F5 to see how it could be improved. Mostly I was looking for two things – better sound and an even simpler circuit. The desire for a simpler circuit is self explanatory – apart from the aesthetic, I imagine that simpler circuits tend to sound better. (Because I build them myself, I will add cheapness and laziness to my motivations.)

I envisioned a circuit with only four transistors and four resistors – the bare minimum for an amplifier of this type, where all the Fets are operated in Common-Source mode, giving both voltage and current gain. Two complementary input Jfets drive two complementary power Mosfets, and the output voltage is fed back to the Source pins of the Jfets in what is commonly called “Current Feedback” (CFA).

The schematic looked like this:



In such a simple circuit, there are opportunities for improving performance by careful choice of transistors, resistor values, voltage and current values and precise matching of parts. I built up a number of such amplifiers evaluating both the measurements and the sound, and after a while a very nice little amplifier emerged. That it (and the F5) resembled Plantefeve's *Profet* was testament to his fine work.

It had most of what was on my wish list:

Very wide bandwidth

Low distortion and noise

Large Class A operating region

Less feedback

No degeneration in the output stage

Very low thermal distortion and drift

No capacitors or transformers (apart from the power supply)

Looks like a great laundry list. I thought the amplifier sounded pretty good, but after a time the consensus was that it was kind of polite, not as musically involving as some other examples. One area where the amplifier fell “objectively” short was the output impedance. Most of your “better” amplifiers have higher damping factors like 20 or 100, and this amplifier was only about 5 or so, typical of a simple Common-Source topology and low negative feedback.

The damping factor, which is the inverse of the output impedance, determines the flatness of the amplifier response when the load impedance varies and is important to the transient response of reactive loudspeakers, which is just about all of them.

You could argue that single-ended tube amplifiers sound good and don't have much damping factor, and you would be right, but I'm not trying to duplicate single-ended tube amplifiers here – the First Watt SIT amplifiers, doing a decent solid-state emulation of Triodes, represent that genre nicely. I'm shooting more for the sound of *The Beast With a Thousand JFETs* but with obtainable parts.

I tried other Fets, varied the the feedback network values and tweaked the gain symmetry. These efforts delivered a little more warmth and dimensionality, and about a year ago I decided to go ahead and build a small pilot run in anticipation of a product release – after all, it was a perfectly *nice* amplifier.

Still, I was not really satisfied, so I created new printed circuit board artwork, adding cascode operation to the input stage and doubling up the output devices. This version had a little more control, but still fell short.

So...

I went back to the original simple design. On the wall in my lab is a little box with a glass window labeled:

DANGER - POSITIVE FEEDBACK

I broke the glass. Inside was a single resistor.

And I put that resistor in the amplifier...

A little explanation is in order. The relationship between an amplifier and a loudspeaker is a bit like a dance. Both sides have their own complexities, but the point is for them to get along well. The amplifier designer, not generally having control of what speaker is used, usually chooses the amplifier as the dominant partner by making it a pure *voltage source*. In the typical *voltage source*, negative feedback in the amplifier is used to define the voltage across the loudspeaker regardless of the current through the speaker.
This represents the “have it my way” approach to amplification, and large hardware with lots of feedback are good at this. Most loudspeakers are designed around the assumption of a low impedance voltage source.

The F7, a nice little Class A amplifier with hardly any feedback does not have the brute force advantage. It resorts to a stratagem that makes the dance a little more like a Tango.

Modest amounts of negative feedback are balanced in counterpoint to small amount of positive current feedback, creating an equilibrium where the output impedance approaches zero, improving transient and frequency response.

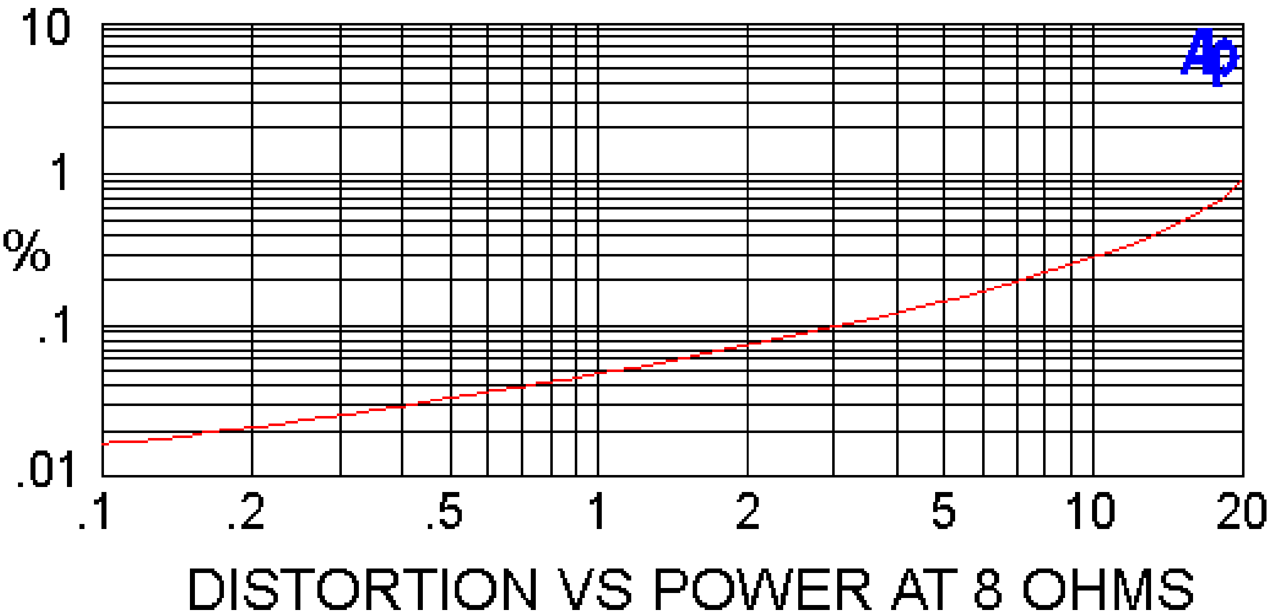
Of course you can achieve a similar effect with tons of negative feedback, but I think this is more elegant and sounds better. For brevity, I will call it “*PCF”.*

Also, I put more capacitance in the power supply and found a clever way to further reduce the effect of high frequency DAC noise and environmental RF.

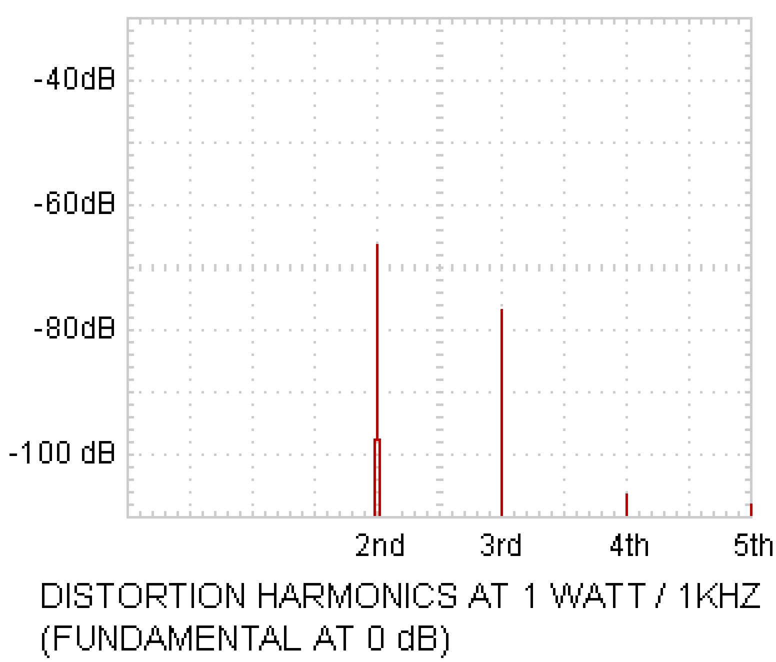
This is a different amplifier. The diversity of audio taste being what it is, not everyone will prefer it. I presume that a portion of audiophiles will like it.

Nothing But the Facts:

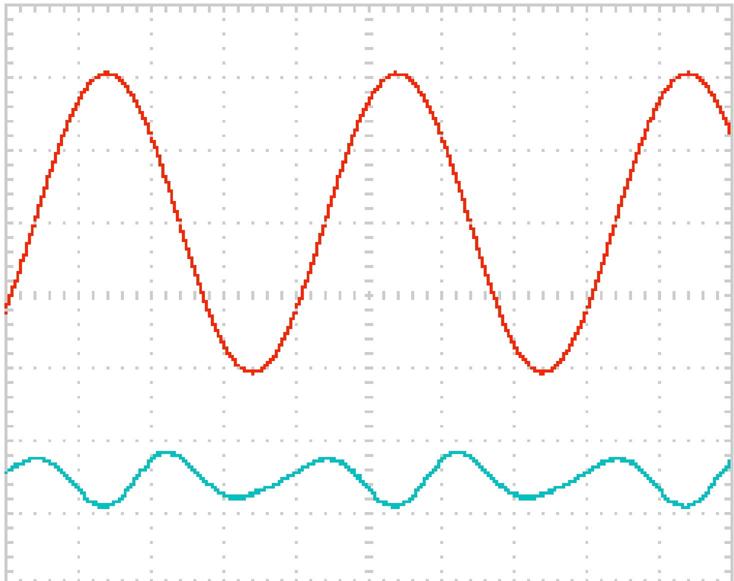
Distortion curve vs output power (1 KHz):



Spectrum of the distortion at 1 watt, 8 ohms and 1 Khz, noting the 10 dB ratio between 2nd and 3rd harmonic:

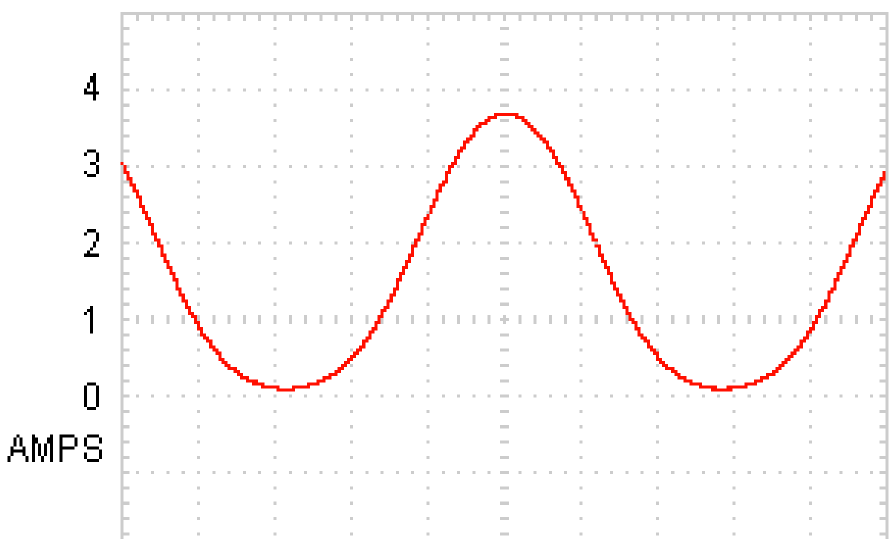


That same test, showing the waveforms of the fundamental 1 watt tone and the distortion:



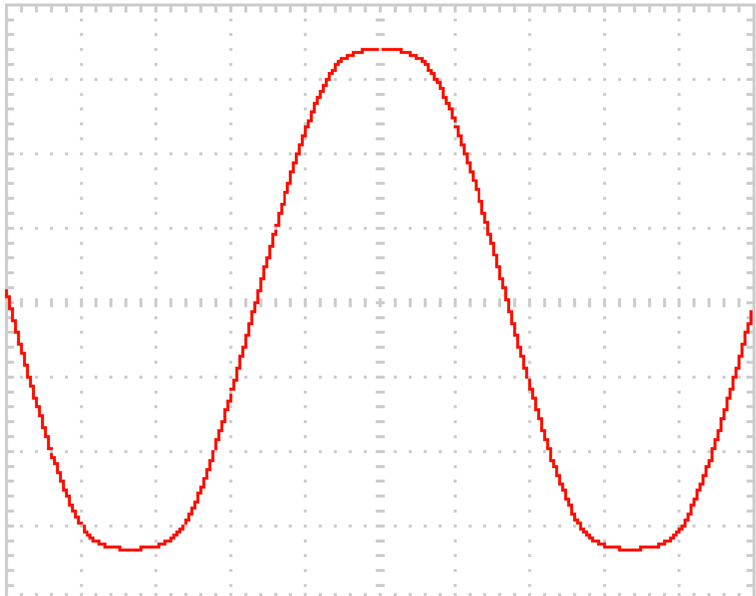
DISTORTION WAVEFORM AT 1 W / 1 KHZ

Output current through half the output stage, leaving Class A at 50 watts peak:



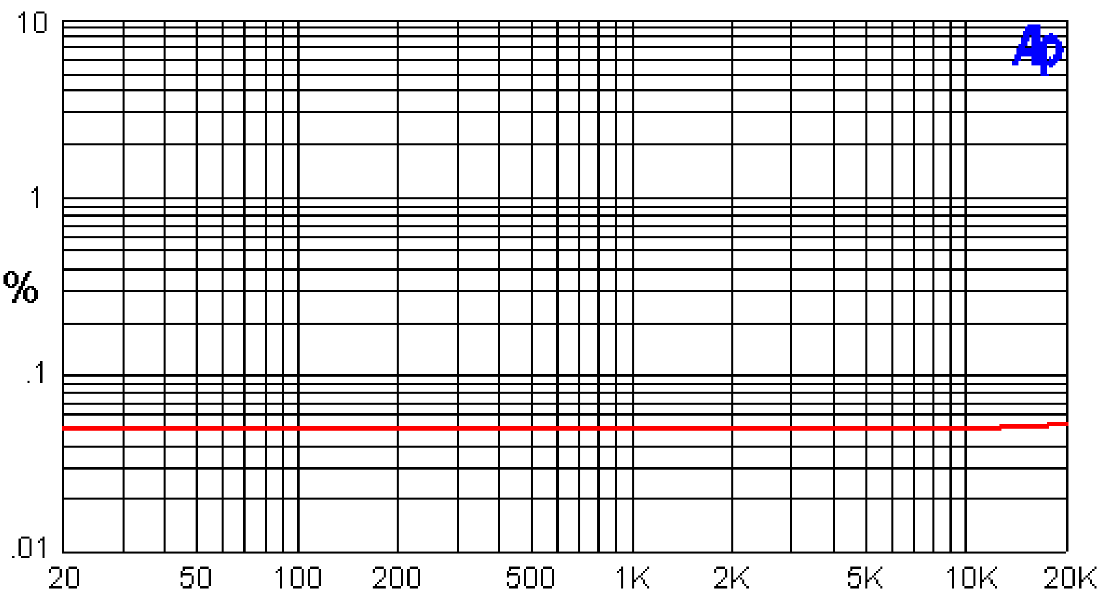
CURRENT FLOW THROUGH SINGLE OUTPUT DEVICE AT 50 WATTS PEAK INTO 4 OHMS

Smooth clipping at 40 watts into 4 ohms:



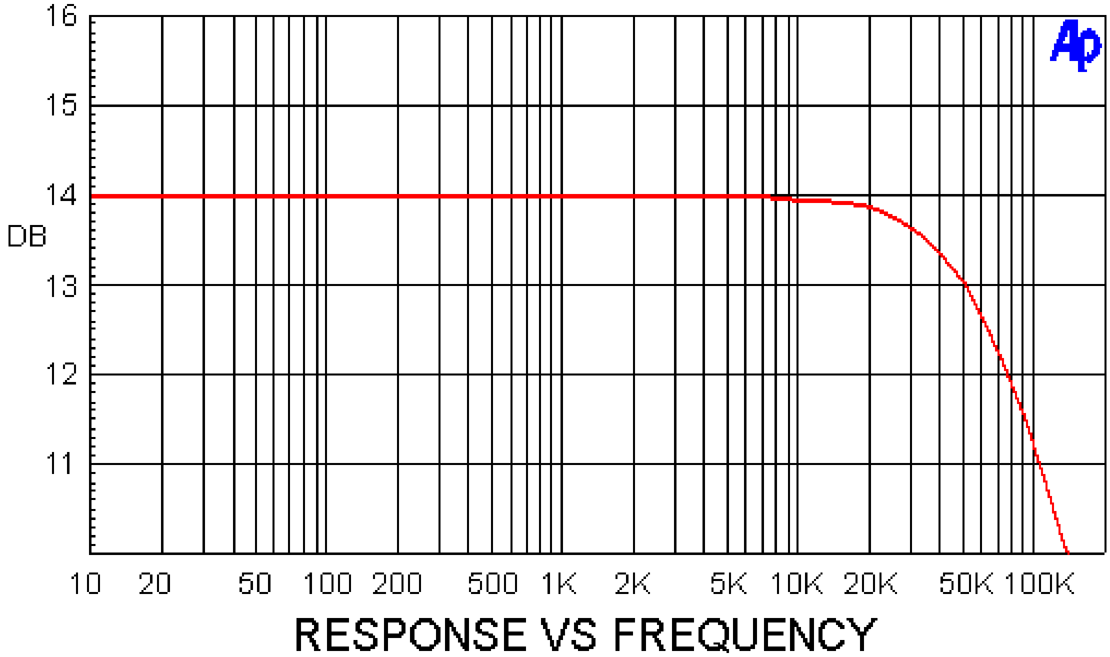
CLIPPING AT 40 WATTS / 4 OHMS

Distortion vs Frequency:

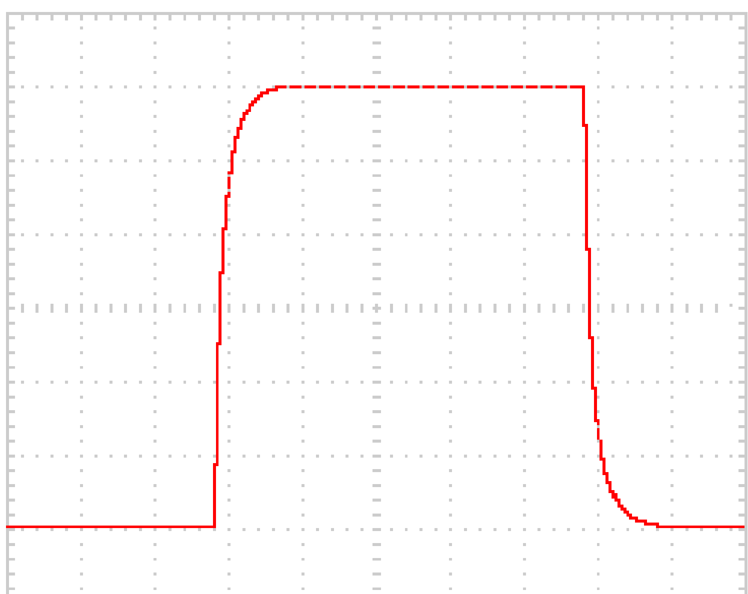


DISTORTON VS FREQUENCY AT 1 WATT

Response vs Frequency:



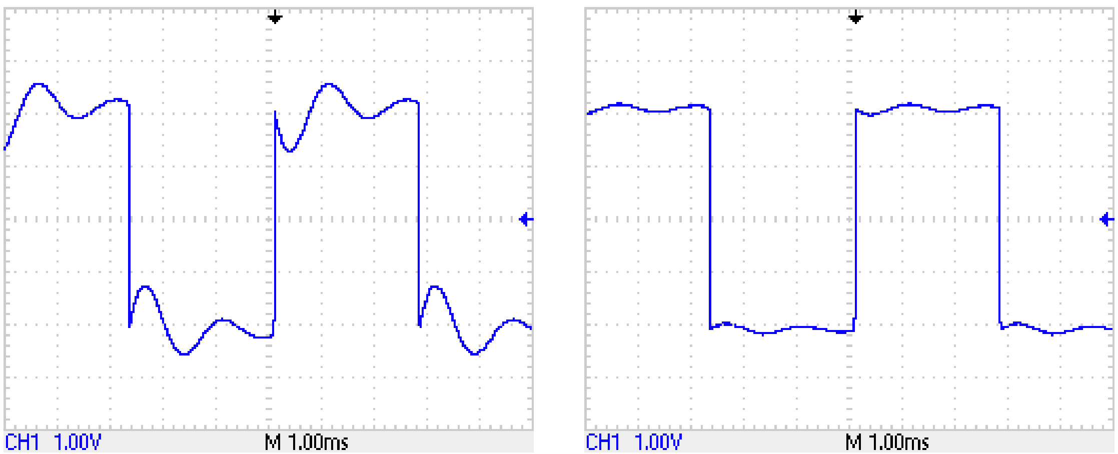
10 Khz Square Wave at 28 Watts:



28 WATT SQUARE WAVE AT 10 KHZ

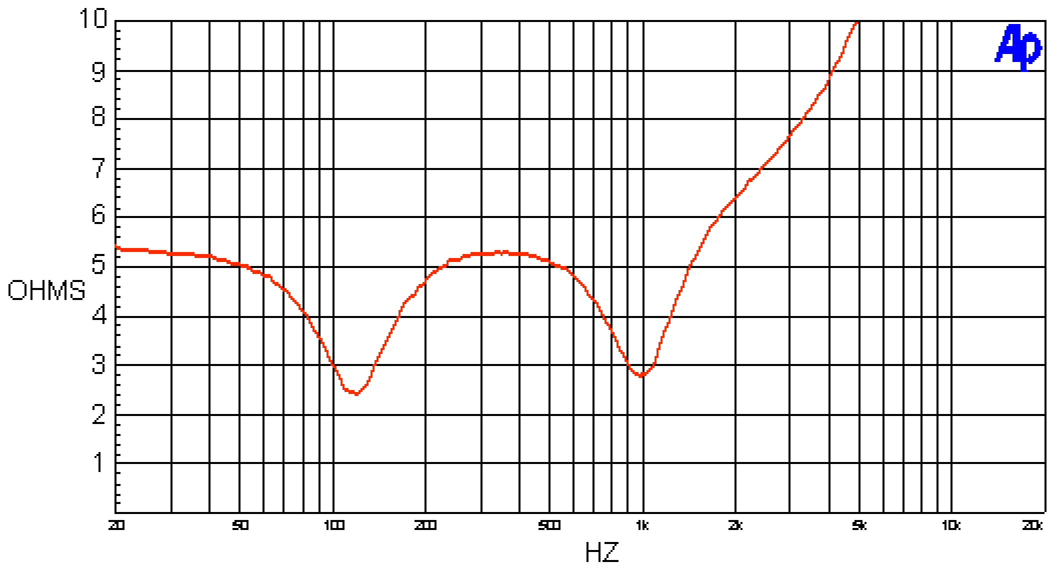
Here's where we get to see some of the differences afforded by a little positive current feedback.

I created a purely reactive loaded using a 1 mH coil in series with a 50 uF film capacitor which resonates at about 700 Hz to an impedance dip well below 1 ohm. Here you see the amplifier driving that load with a 180 Hz square wave – showing the ringing induced. The improvement in control is readily apparent.



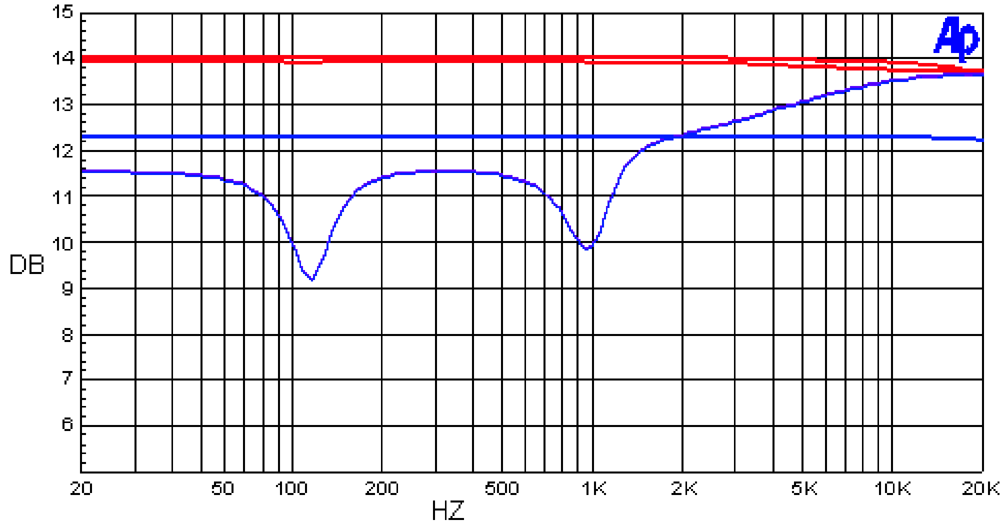
F7 SQUARE WAVE INTO 1MH + 50 UF SERIES LOAD
RIGHT = WITH POSITIVE CURRENT FEEDBACK

I also created a difficult test load reflecting an amalgam of the sorts of things seen in several popular loudspeakers. Here is the impedance of that load, dipping down below 3 ohms at two points:



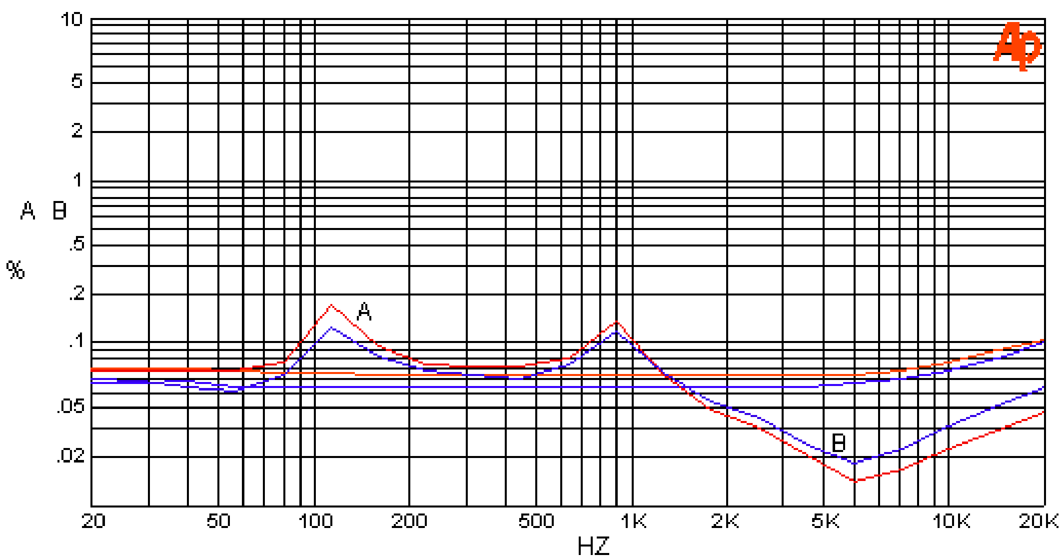
IMPEDANCE OF TOUGH LOAD

And here is the response of the amplifier into this load with and without pcf.



RESPONSE INTO 8 OHMS AND TOUGH LOAD
UPPER = WITH POSITIVE CURRENT FEEDBACK
LOWER = WITHOUT

How's the distortion when pcf is applied? Here is a distortion vs frequency plot of that amplifier into 8 ohms and also the tough load. With or without PCF, we see that the distortion goes up a bit when confronted by 2.5 ohm loads, but this is a expected from any amplifier – more power is being delivered at those impedances, particularly from the amp with PCF, whose output voltage is not sagging.



1 WATT THD VS FREQUENCY WITH 8 OHMS / TOUGH LOAD
A = WITH POS FEEDBACK B = WITHOUT

Nominal specifications:

Measured at 120 V AC and an 8 ohm load:

Distortion @ 1 watt	0.05%
Input Impedance	10 Kohm
Gain	14 dB (X 5)
Input Sensitivity (1 watt)	0.57 V
Input Sensitivity (max output)	2.53 V
Damping Factor	>100
Output power 8 ohms	20 watts @ 1% THD, 1KHz
Output power 4 ohms	30 watts @ 2% THD, 1KHz
Class A envelope	50 watts peak @ 4 ohms
Frequency response	-3 dB @ 100 KHz
Noise	100 uV unweighted, 20-20 KHz
Power consumption	160 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.

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

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.

Once Again:

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