FIRST WATT

F2 POWER AMPLIFIER

6/16/2005

It has been about 9 months since the introduction of the First Watt F1, and I have been very surprised to see everything going more or less according to plan. I am just finishing up the 100 amplifiers of that design (about 10 per month), and there are only a few left before they cease to be available as new. The reviews have been uniformly enthusiastic, the customers seem happy, and none have broken yet.

So I am pleased to move on to this next design, the F2. Like the F1, it is a current source, although less of one since I put 15 ohms across its output terminals to give it a slight damping factor – 0.5 instead of the 0.1 of the F1. I surmise that most customers will be happier with this without having to put resistors across the output.

Most customers also have no use for balanced inputs, which is fine because the purely single-ended F2 circuit cannot use a balanced signal in any case.

While the F1 had a crisper sounding 3rd harmonic signature, the F2 has a richer 2nd harmonic character, one that is sufficiently different to justify another version of a current source amplifier.

Anyway, I'm only going to make the 100, and future amplifiers from First Watt are currently planned as voltage sources.

If you bought this amplifier, thank you very much. Even if you didn't buy it, your comments and questions are welcome.

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Introduction

The F2 is a two channel transconductance power amplifier, which is a fancy name for an active current source.

A given input voltage results in a particular output current. Ordinary amplifiers are voltage amplifiers – an input voltage translates into an output voltage. This is not that kind of amplifier, and as of this writing, the F1 and now the F2 are the only such amplifiers available for audio use.

Being current sources, these amps operate differently with a loudspeaker. A regular audio amplifier supplies an arbitrary output voltage, and the speaker draws current according to its complex characteristic. As such, the current through the loudspeaker is not exactly proportional to the voltage in either amplitude or time.

A current source amplifier delivers a precise current to the voice coil of the loudspeaker driver, ignoring the series impedance elements in the circuit, including the wire, connectors, the inductance of the voice coil, the resistance of the voice coil versus temperature – all that stuff.

This is potentially valuable in that the current passing through the magnetic field of the loudspeaker produces the force and acceleration on the voice coil and cone, and this translates directly into sound pressure. A current source is simply the most direct way of controlling the acceleration of the voice coil. In the linear range of a loudspeaker, the acceleration is directly proportional to the current, and in mass-controlled loudspeaker drivers the sound is proportional to the acceleration.

Since most loudspeaker systems are designed around a voltage source, there is only a subset of products that can take advantage of this effect. In general, these are high-efficiency drivers (ones that produce more than 90 dB per watt). Of greatest interest is the performance offered to high-efficiency full-range drivers, where not only is the loudspeaker very efficient, but also covers a wide or full range of the audio spectrum through a single radiating surface.

Often this translates to delicate single cone drivers such as the products from Lowther or Fostex, with big motor assemblies coupled to light fragile paper cones. These are the speakers that often don't sound good with "high quality" solid-state amplifiers, most often because the two are mismatched in impedance and wattage.

This is an unusual amplifier that will not give its best performance with most of the loudspeakers on the market. It requires careful attention to loudspeaker loading to get the best performance. The accompanying white paper “Current Source Amplifiers and Full-Range High-Efficiency Drivers” is required reading. This is a tinkerer’s amplifier.

If being a current source amplifier isn’t different enough, the F1 and F2 are special in other ways. In particular, they use no feedback to reduce distortion, flatten frequency response or create a low output impedance, and they ignore the voltages that appear across the speaker terminals.

Not having feedback does result in an amplifier that has more harmonic distortion, but it also avoids the subjective artifacts that come with feedback. I think of feedback the way I think of a credit card – a handy thing to have, but the bill always arrives at the end of the month.

Paradoxically, amplifiers which sound best with feedback are already very linear and don’t particularly need it. In the real world, feedback is usually excessively used to patch up the performance of a very non-linear circuit.

In any case, the distortion of these circuits is low enough to compare with loudspeakers and other elements in the signal chain, and the amplifiers are designed to sound natural while carrying finely recorded music.

They have only one gain stage, not 2 or 3 or 4 or 9., and they operate in pure class A mode, which is the very best, but at a cost of drawing roughly 10 times their rated output.

They are probably the quietest amplifiers you can buy, with typical figures of about 100 pico-watts noise. A pico-watt is a trillionth of a watt.

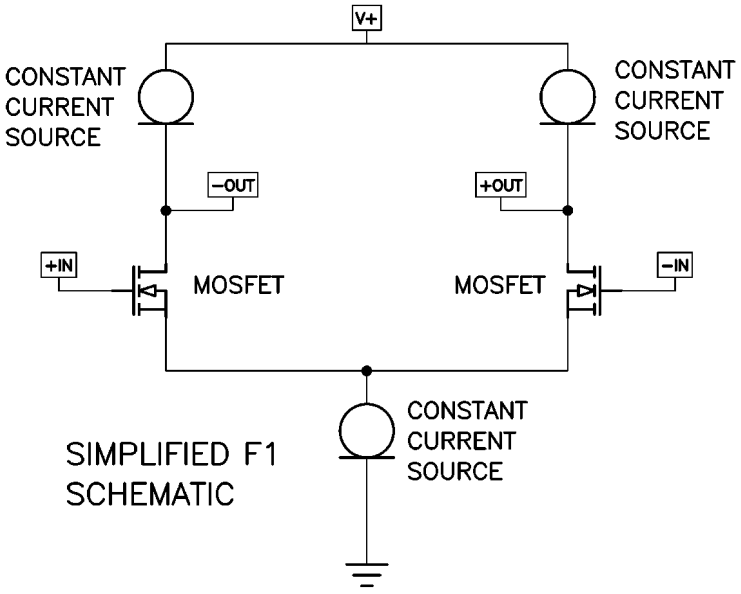
That’s how the F1 and F2 are different from other amplifiers.

So what is different about the F2 compared to the F1?

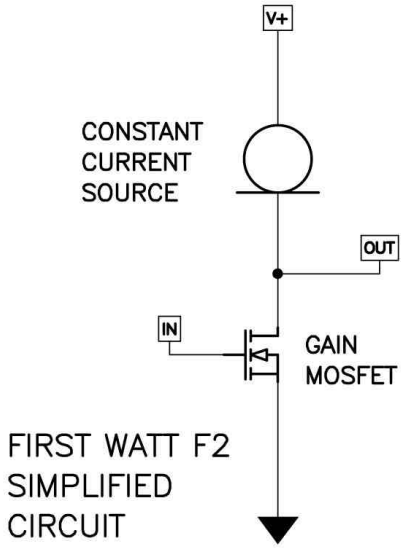
The F2 was created to do some things differently than the F1.

The F1 is best described as a “balanced single-ended Class A” amplifier, in which a single “differential pair” of transistors are biased by three constant current sources, and operated without feedback in the audio band.

As such, the F1's dominant form of distortion reflects the symmetry of the gain stage, and that would be the 3rd. What would have been the 2nd harmonic of the gain devices is largely cancelled by the symmetry of the gain stage. You can see this left/right symmetry in the following simplified schematic:



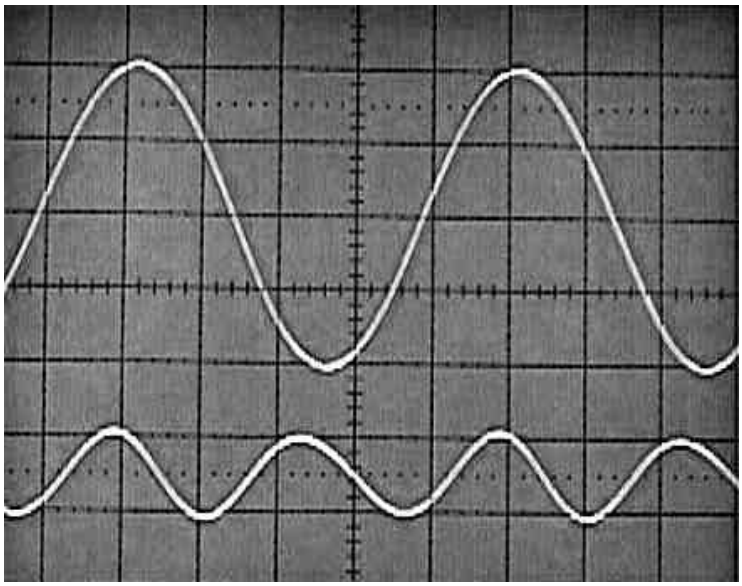
The F2 is best described as a single-ended Class A amplifier operated Common-Source and biased by a constant current source. It is simpler than the F1 as seen in the following simplified schematic:



Here you can see that the signal goes in the Gate of a Mosfet and comes out the Drain. Practically speaking, you cannot build a simpler amplifier.

Its distortion character is a fairly pure 2nd harmonic that gives it more resemblance to the classical single-ended tube amplifiers that have traditionally been popular with high-efficiency wide range speakers.

Seen on a distortion analyzer, the F2 looks like this, where the top trace is 1 kHz into 8 ohms at 1 watt, and the bottom trace is the distortion at about 1%. Notice the absence of noise and higher harmonics.



It's interesting to investigate the difference in sonic character that comes from a 2nd versus 3rd harmonic character. Conventional wisdom descended from tube amplifiers has it that 2nd harmonic is known for its warmth and romantic character while 3rd harmonic offers greater dynamic range and clarity.

While these observations don't necessarily apply to solid-state amplifiers, they pretty much correspond to the sounds of the F1 and F2. If you prefer a good push-pull tube, you are more likely to want the F1. If you like the more lush midrange of a single-ended triode, you would probably gravitate toward the F2.

I am not using those comparisons to suggest that I am trying to emulate tube amplifiers, rather I want to give some basis for understanding the differences between these two topologies whose technical descriptions are otherwise similar. The F1 and F2 are not intended to sound like tubes – they do some things better than tube circuits, and some not as well.

There are other differences between the F1 and F2. While the intrinsic output impedance of the F2 is several hundred ohms, I have loaded the output with 15 ohms of resistance to give it a finite source impedance. I did this because (from the experience of many F1 customers) it is highly unusual to want a damping factor of less that 0.5, and some customers who did not load the amplifier at all experienced a lack of bass control.

Not a problem – I put in the first 15 ohms of loading for you so that your out-of-the-box experience will be better. If by chance you don't want even the 15 ohms, it can be removed, and you can have about 700 ohms instead.

Another difference is that there is no balanced XLR input connector. Well, that's no surprise, is it?

At 5 watts into 8 ohms the F2 is less powerful than the F1, but it is biased at nearly twice the current, so it does a better job into 4 ohms, and can more easily drive some of the correction networks that you might use to adjust your speaker's response. My own experience is that the kinds of speakers this amplifier is intended for are usually happy within a 4 watt window.

The F2 starts showing higher harmonics above 4 watts (8 watts peak) into 8 ohms and measures about 4% distortion at 5 watts. Into 4 ohms it will clip at about 10 watts (20 watts peak) with about 9% distortion.

This is also a very fast amplifier if your source has a low output impedance – check out the 10 KHz square wave on page 14.

Like I said, this is an unusual power amplifier. Like the F1, there will be 100 F2's offered for sale, and no more.

I built this amplifier myself. No, I didn't extrude the aluminum or etch the circuit boards, but I bolted and soldered the parts together and tested each one with loving care. Each amplifier has spent time in my system burning in and being listened to.

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

nelson@passlabs.com or www.firstwatt.com

Setup – Read This

Be certain to look at (or even read) the attached white paper "Current Source Amplifiers and Full-Range High-Efficiency Drivers" in considering how to use this amplifier. It is designed for a particular type of loudspeaker, and may not sound good with others. There is no potential for damage to the amplifier and you are not likely to break the speaker, so go ahead and try any speaker you like - just don't be surprised if it doesn't suit you.

The initial setup of the amplifier is very straight-forward. Place the amplifier in a well-ventilated location, as it draws 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 power to the channel. On the rear panel you will find pairs of RCA inputs, speaker outputs, a fuse holder, and AC power receptacle, and on/off switch and a label.

The label will indicate a serial number that is from #0 to #100 and also indicates 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 4 amps. If the voltage is 240 VAC, then the fuse will be rated at 2 amps.

(If the label on the back says "Property of First Watt" then this amplifier was not intended for sale and is not new and carries no warranty.)

The fuse is a 3AG slow blow type, 4 amp for 120 VAC and 2 amp for 240 VAC. No substitutions. 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.

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.

At this point you should be able to listen to music. This amplifier has less gain than most, but at 5 watts rating, it doesn't 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 supplies of each channel are isolated from each other electrically, except for a thermistor on each which connects the circuit ground to the chassis and earth ground. In this way ground loops are prevented, as the channels will typically share ground only at the source, but the thermistors stand by to conduct AC line voltage to ground until the fuse blows, in case of transformer or other such failure.

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, as the performance difference between 5 minutes and 60 minutes is very marginal. I do not personally see a reason to run the amplifier all the time.

While the gain is low, the input impedance of the amplifier is high, about 50 Kohms, depending slightly on the load impedance, so you should find it easy to drive with tube equipment if you like.

The F2 will usually work fine with passive crossover networks for wide-range drivers with tweeters. For those of you interested in designing passive crossover networks, check out the article on crossover networks for current source amplifiers on the web site.

One thing that you are likely to notice about the F2 is its phenomenally low output noise, typically about 50 pico-watts (a pico-watt is a trillionth of a watt) un-weighted across the audio band. It is quieter than many preamplifiers.

If you are familiar with the Zen amplifiers published over the past 8 years or so in AudioXpress, then you will see a passing similarity to the original Zen, except that the F2 uses no feedback, has a much higher input impedance, and is much quieter.

Like the Zen, the amplifier has a simple 2nd harmonic distortion characteristic, what we expect from a one stage single-ended design.

Now the following is for your protection, so pay attention:

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, turn it off and get a qualified technician to look at it. If you can't touch the heat sinks for 5 seconds or so, consult First Watt or a qualified technician.

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, consult the factory or a qualified technician.

If you have a problem, contact me. I am much happier fixing anything myself so that I can be certain that it's done properly. My experience is that most repair efforts done by amateurs in the field do more harm than good.

Summary of the nominal specifications:

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

Input Impedance	50 Kohms
Output impedance	15 ohms
Output power 8 ohms	5 watts @ 4% THD 1KHz
Output power 4 ohms	10 watts @ 9% THD 1KHz
Gain	15.6 dB
Maximum output voltage	+/- 9 volts
Maximum output current	+/- 2.4 amps
Frequency response	- 1 dB @ 3 Hz, 200 KHz
Noise	20 uV unweighted, 20-20 KHz
Power consumption	150 watts (~75 watts / channel)
Fuse	3AG slow blow type, 4 Amp for 120VAC 2Amp for 240 VAC

Warranty: Parts and labor for 3 years, not covering shipping or consequential damages. This amplifier is a specialty product. There is no representation that the amplifier will make you a happy person.

Zen amplifier is a trademark of Pass Labs, Inc.

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Contact:

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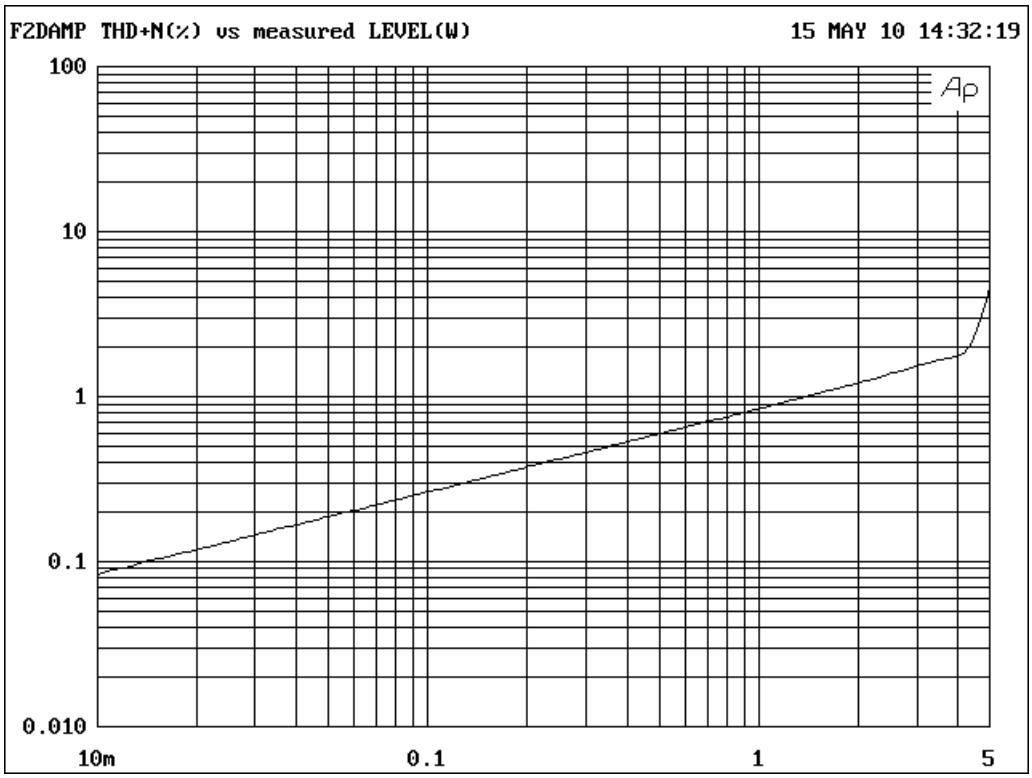
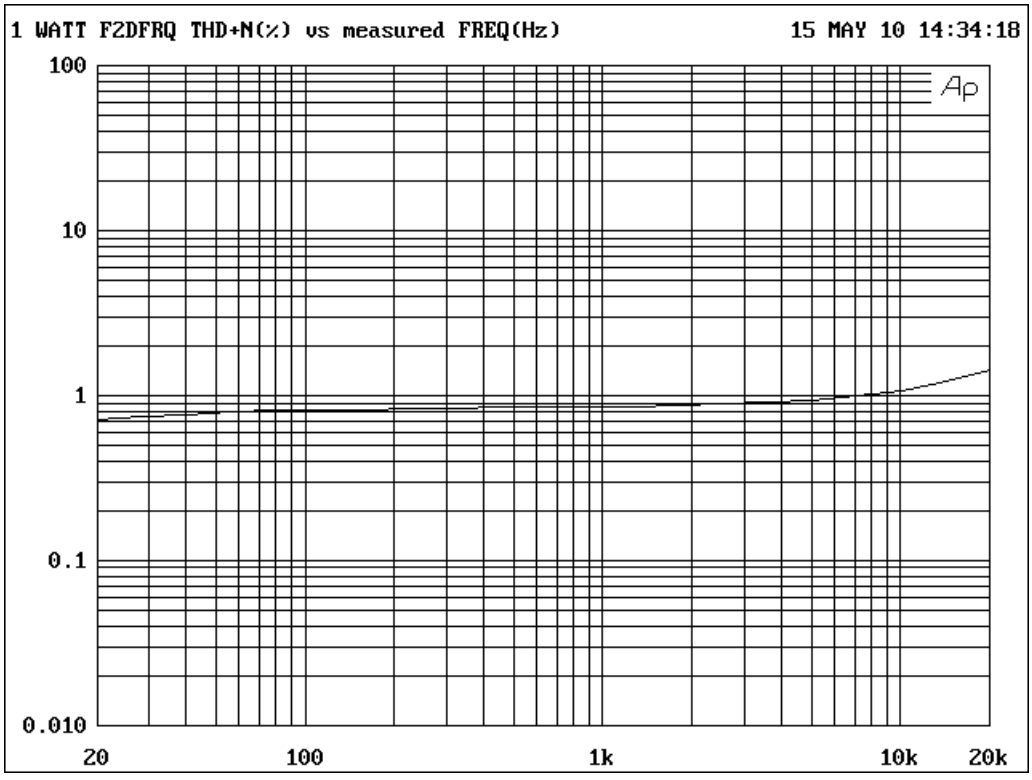
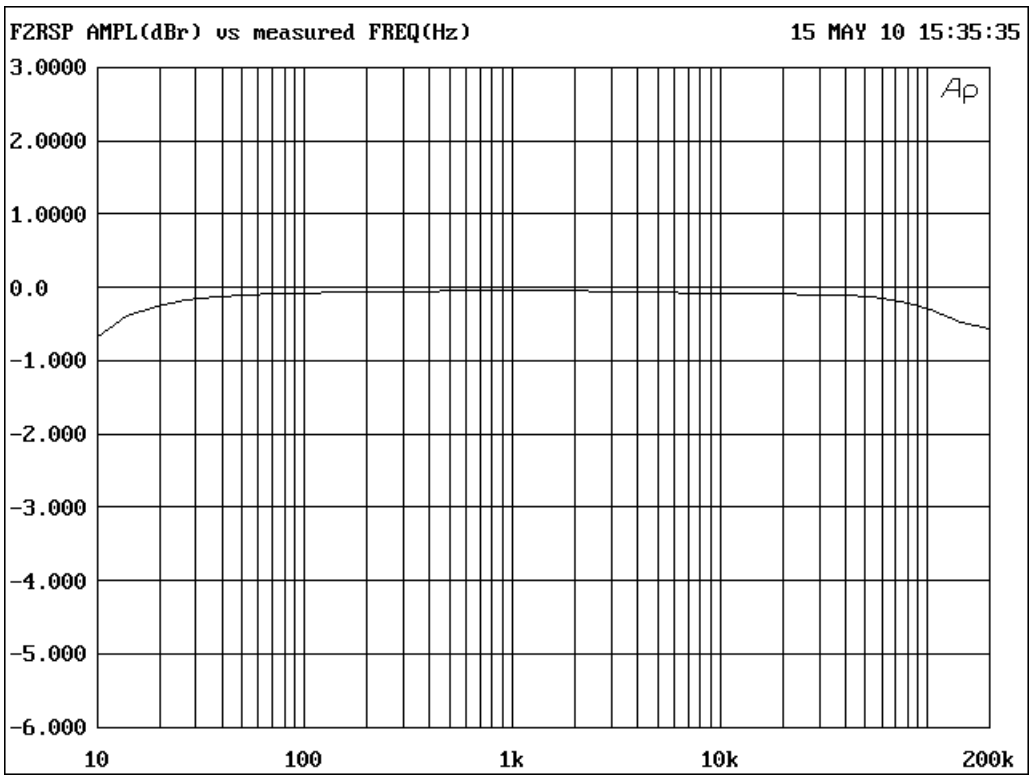
Typical performance curves:



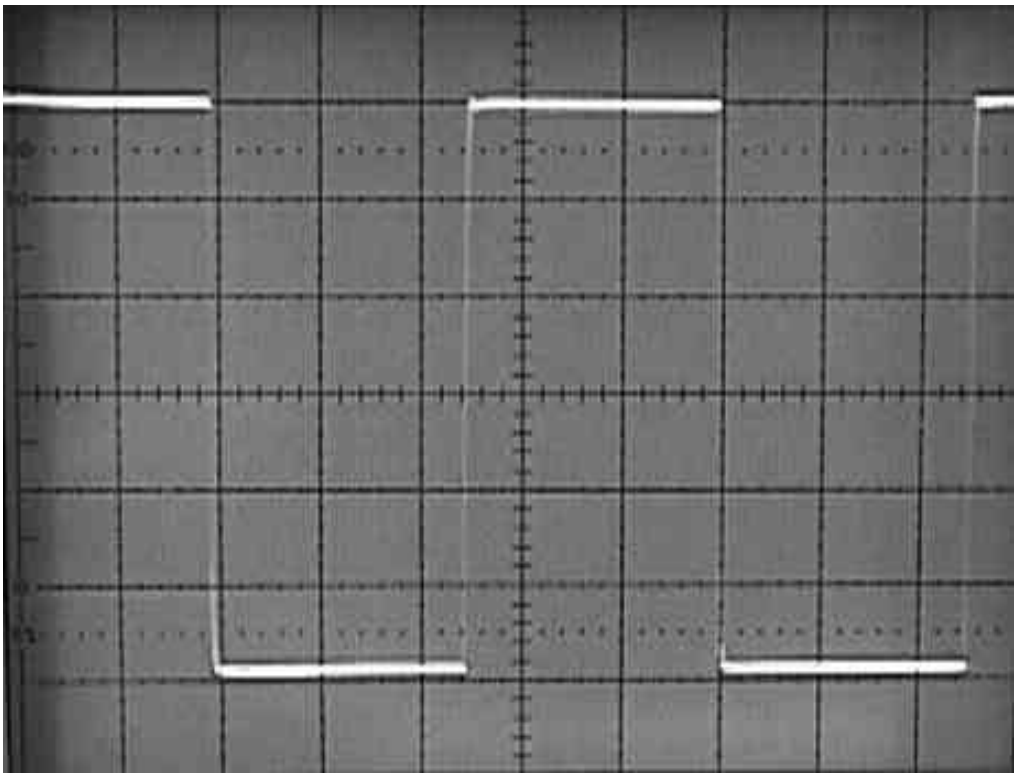
DISTORTION VS WATTS @ 1KHZ



DISTORTION VS FREQUENCY @ 1 WATT



FREQUENCY RESPONSE



10 KHZ SQUARE WAVE @ 3 VOLTS