

The Sony VFET Amplifier 40 Year Commemorative

By Nelson Pass

Introduction

This is about audio power amplifiers, more specifically about those made with a special type of transistor known originally as a VFET, now more commonly referred to as a Static Induction Transistor (SIT).

In the 1960's silicon power transistors began to replace tubes in audio power amplifiers, being more convenient in a number of ways. The transistors themselves were smaller, less costly, more efficient and they needed less external hardware to make them work.

There were some complaints about their sonic performance in audio amplifiers as compared to tubes, and some efforts were made to give transistors a more "Triode-like" character.⁽¹⁾ Similar efforts and discussions about them continue to this day.

In 1972 a U.S. patent application was filed by Junichi Nishizawa describing a special type of JFET (Junction Field Effect Transistor) where the "drain-current to drain-voltage characteristic simulates the anode-current to anode-voltage characteristic of the triode vacuum tube very closely."⁽²⁾

Examples of "VFETs" were produced by Sony and Yamaha forty years ago and appeared in power amplifiers produced from about 1975 through 1980⁽³⁾. These amplifiers are now prized for their exceptional sound, the credit popularly going to the linearity of the VFETs⁽⁴⁾. They were called VFETs at the time because they have a vertical (not lateral) structure. The subsequent invention and dominance of vertical MOSFETs (Metal Oxide Semiconductor Field Effect Transistor) made use of the term confusing, so now they are generally referred to as Static Induction Transistors (SIT), except perhaps as reference to these original parts.

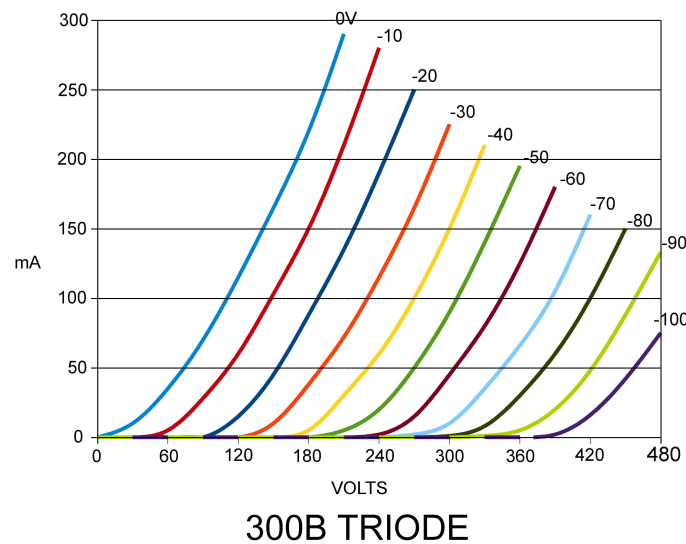
These transistors were also exceptionally fast as switches, and in 1976 Sony also produced an early version of the Class D audio amplifier, the TA-N88.⁽⁵⁾⁽⁶⁾

By the 1980's Sony and Yamaha ceased production of VFET amplifiers. Various reasons for this have been offered, the most likely being that production of these exotic parts was considered too expensive to compete with the cheaper vertical MOSFETs which appeared on the market.

Why VFETs?

It's all about the curves. The properties of a gain device are often described by lines on a two dimensional graphic. The location and shape of these lines can give some insight into the performance of the part, providing a map of the territory, the “roads, rivers, hills and valleys”, which the gain device navigates while doing the job of amplifying the audio signal.

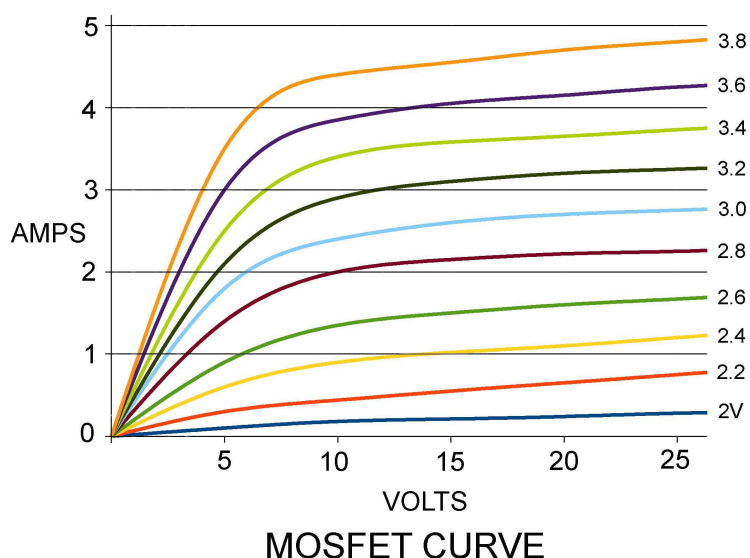
For a tube, this could be a graph of the amount of current going from the Plate to Cathode versus the voltage from Plate to Cathode at a given voltage between the Grid to Cathode. Here is an example for a power Triode:



The vertical axis is the current in milli-Amperes, and the horizontal axis is the Plate to Cathode voltage. The multicolored family of lines show how the current through the tube varies with voltage for eleven examples of a fixed Grid to Cathode voltage from 0 Volts to -100 Volts. These curves have a shape common to all triodes.

We see in these curves that the current through the device is dependent on both the voltage across the device and also the “control” voltage, which is the voltage between the Grid (control pin) and the Cathode of the tube. In this sense we can imagine the Triode acting as if it were a voltage-controlled resistor, that is to say that the tube acts somewhat like a resistor whose value is dependent on the voltage between the Grid and the Cathode. If you vary the voltage, then the apparent resistance of the Triode varies, and current flows through the tube in proportion to the voltage across the Plate and Cathode. In this way, amplification of a signal is achieved.

The Triode curve is contrasted with the curve of a typical MOSFET transistor:



Here we see the curves of the current going from Drain to Source (vertical axis) versus voltage from the Drain to Source pins, each colored line reflecting a different voltage from the Gate to Source pins. The tube/FET pins are analogous: Plate/Drain, Cathode/Source and Grid/Gate.

You can see that the lines are flattened out. The current through the MOSFET from Drain to Source is less dependent on the Drain-Source voltage and the device is a voltage-controlled current source. The current through the device is mostly dependent on the Gate to Source voltage.

Of course this is also a very useful device for amplification, and you will find many amplifiers using MOSFETs just as you will also find many amplifiers using Bipolar transistors, whose characteristics bear some similarity to FETs except that they are mostly *current-controlled* current sources, not *voltage-controlled*.

And there are tubes that look a lot like MOSFETs – they are called Pentodes.

By way of cutting through what may be mounting confusion for the reader, I will simply say that each of these types of device has a type of curve, and each type of curve tends to give rise to a characteristic sound. On top of that, each type of device can be used in many ways, giving a very rich variety.

Audiophiles tend to have opinions about the subjective qualities of these devices and circuits. A sizable minority of the audiophile population favors the sound of tube amplifiers, and many of those prefer the sound of Triodes.

Another thing that tubes do not do is that there are no mirror image devices. The Plate is always positive with respect to the Cathode, and until we invent a Positron tube, it is likely to stay that way. However, transistors can be made as complementary (mirror image) parts, and the 2SJ28 is like the 2SK82 but with all the voltages and currents in reverse. This is very convenient, as it makes it very easy to build direct-coupled push-pull amplifiers with simple circuits.

Here is a photo of a pair of those Sony 2SK82 and 2SJ28 complementary matched pairs, part of inventory which sat on the shelf for the last forty years.



So I began working with these transistors as well, and the first result was an amplifier presented at the 2013 Burning Amp Festival in San Francisco. It was a push-pull Class A circuit consisting of only three parts, one each of the 2SK82 and 2SJ28 and a small Jensen coupling transformer. (This did not count the power supplies). It delivered 20 watts at reasonably good gain and low distortion and did so without feedback. I am told that it sounded very good, and it is the subject of a separate upcoming article.

Having only a limited inventory, it occurred to me that the best use of these parts would be to make a modern version of a high power VFET amplifier in commemoration of their introduction forty years ago. Having used the Sony AR-1 loudspeakers at CES, it was a natural that we should make the amplifier as a match to them, and so this project was begun.

It was not trivial, as the AR-1's are a discerning load, requiring relatively high power and control, something not offered by my little three part circuit.

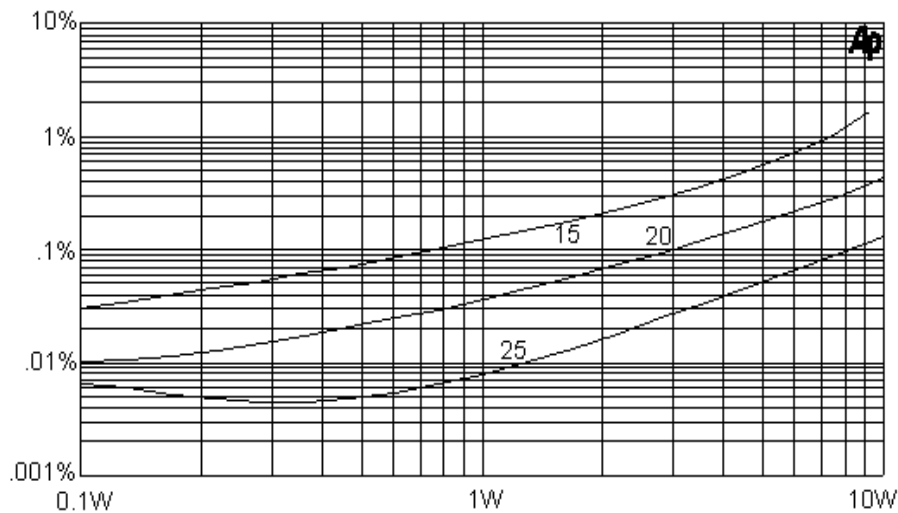
I decided to go with Sony's original approach, parallel complementary followers. This approach was fairly obvious, as complementary followers can deliver much more current than single-ended circuits, and followers will deliver lower distortion than devices operated for voltage gain.

A couple things were to be different, the amplifier was to be operated in Class A mode with a balanced circuit from input to output, and there would be more paralleled VFETs than used in the originals.

Also, in keeping with maximizing the square-law character, I wanted to operate the VFETs without any degeneration, that is to say no Source resistance in the signal path. This better preserves the Triode nature of the parts and extends the Class A operating region by a substantial amount for more Class A power into the four ohm AR-1's. To work well, it requires careful matching of devices.

Fortunately these parts have a near-zero temperature coefficient. They require no thermal compensation and can be relied to give the same performance over a wide temperature range without altered performance.

Here is an example of a single pair of Sony 2SK82 and 2SK28 operating push-pull without feedback:

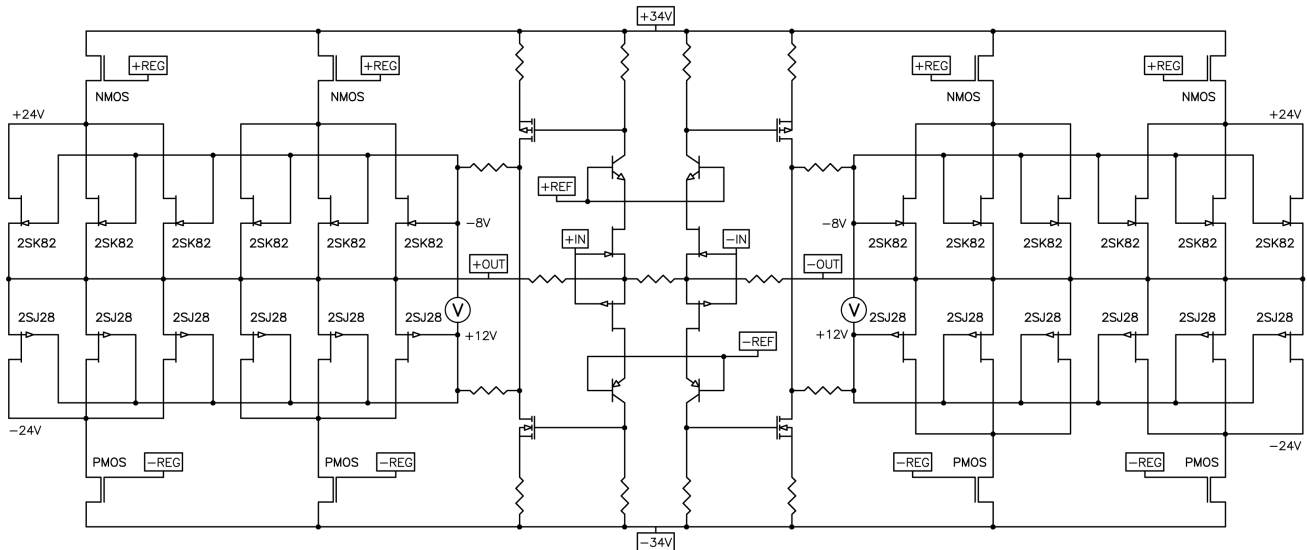


2SK82/2SK28 PUSH-PULL FOLLOWER
1A BIAS, 8 OHM, 15 - 25 RAILS

The distortion is quite good at a 25 volts rail and running something like 25 watts per device. Of course to get much more power, it needs to use more devices operating parallel in two balanced stages. In the end, I used 24 devices for each channel.

Using the resources of Pass Labs we put these output stages into large chassis with big heat sinks and large regulated power supplies with a classically conventional front end voltage gain stage.

Here is the simplified schematic of one channel.



SONY VFET 40 YEAR COMMEMORATIVE AMPLIFIER – SIMPLIFIED SCHEMATIC
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You can see the two balanced halves of the amplifier which offers symmetry between the plus and minus audio polarity as well as symmetry with respect to the plus and minus supply rails. The front end is designed with enough open loop gain to have about 10 dB left over for feedback around the output stage.

I ran the input JFETs without degenerating resistors between complementary pairs in keeping with the emphasis on the “square-law” character of the parts and to maximize their bias current. They are cascoded by Bipolar Toshiba devices at fixed references. The input JFETs and the voltage amplifying MOSFETs are “new old stock” Toshiba parts, hoarded after they were discontinued.

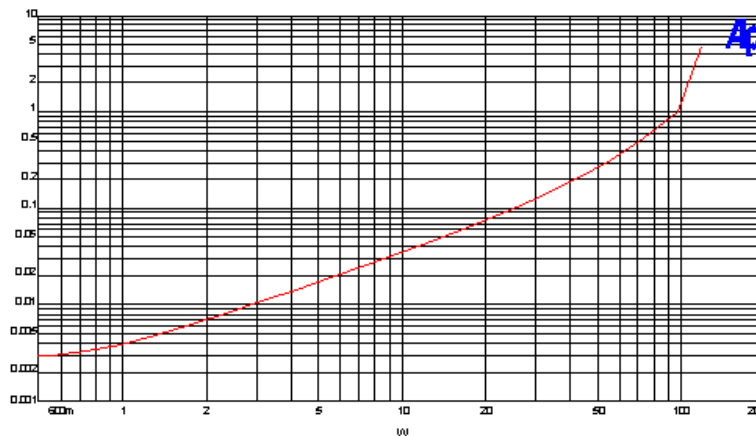
The second stage MOSFETs are operated at a relatively high bias current in order to adequately drive the capacitance of the banks of parallel devices.

The front end has a 100 KHz bandwidth and an output impedance of about 600 ohms. Distortion which occurs in the output stage at higher frequencies reflects the nonlinear capacitance of the output devices, not a variation in feedback. The circuit is DC coupled and there are no compensation capacitors.

Because the nature of the VFET as a voltage controlled resistor, the best performance is obtained with regulated power supplies, and for this we use 8 power MOSFETs to stabilize and filter the supply rails. An advantage to the regulated supply is that it can be made to bring up the rail voltages slowly, allowing time for bias circuits to stabilize. Depletion-mode SIT transistors, like tubes, are “normally on” which means that instead of encouraging them to conduct, we have to supply a voltage to “rein them in,” and this must be in place when the output stage receives access to power.

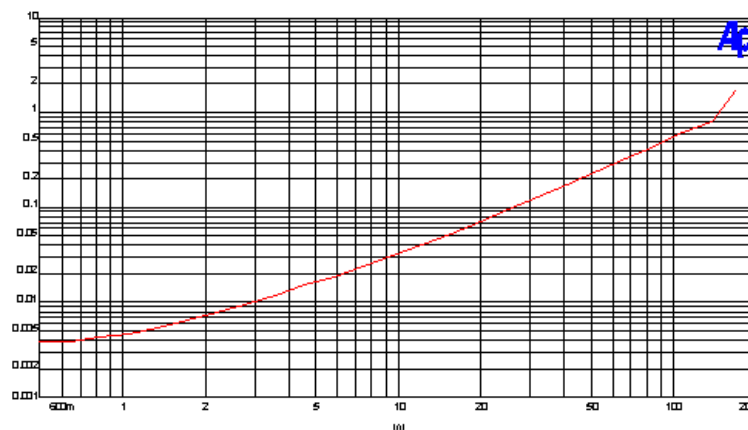
This amplifier has about a 6 amp bias, and draws about 400 watts from the wall at idle. The output stage leaves Class A at about 8 amps peak, which is enough to do about 250 watts peak into 4 ohms.

Here is the distortion curve into 8 ohms:



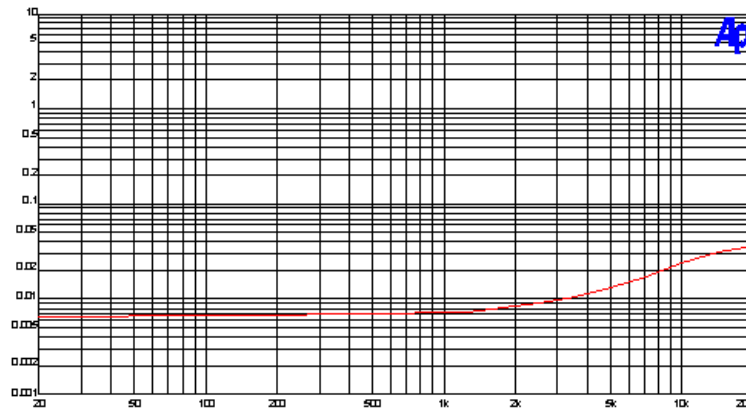
SONY VFET AMP - DISTORTION VS OUTPUT 8 OHM 1KHZ

Here is the distortion curve into 4 ohms:



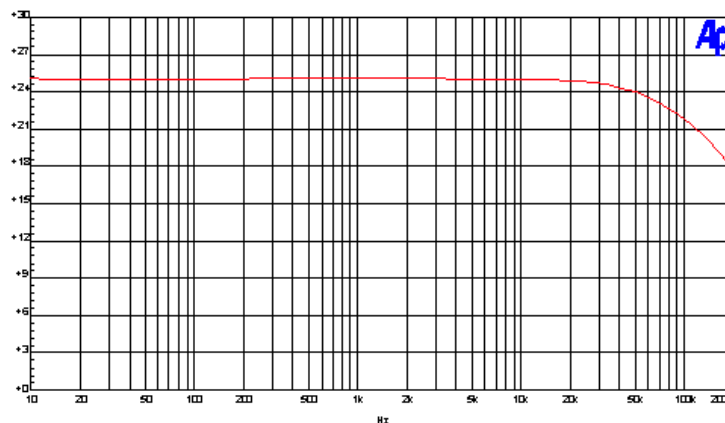
SONY VFET AMP - DISTORTION VS OUTPUT 4 OHM 1KHZ

Here is the distortion versus frequency, showing the effect of non-linear output stage capacitance:



SONY VFET AMP - DISTORTION VS FREQ - 8 OHM 2 WATT

Here's the frequency response:

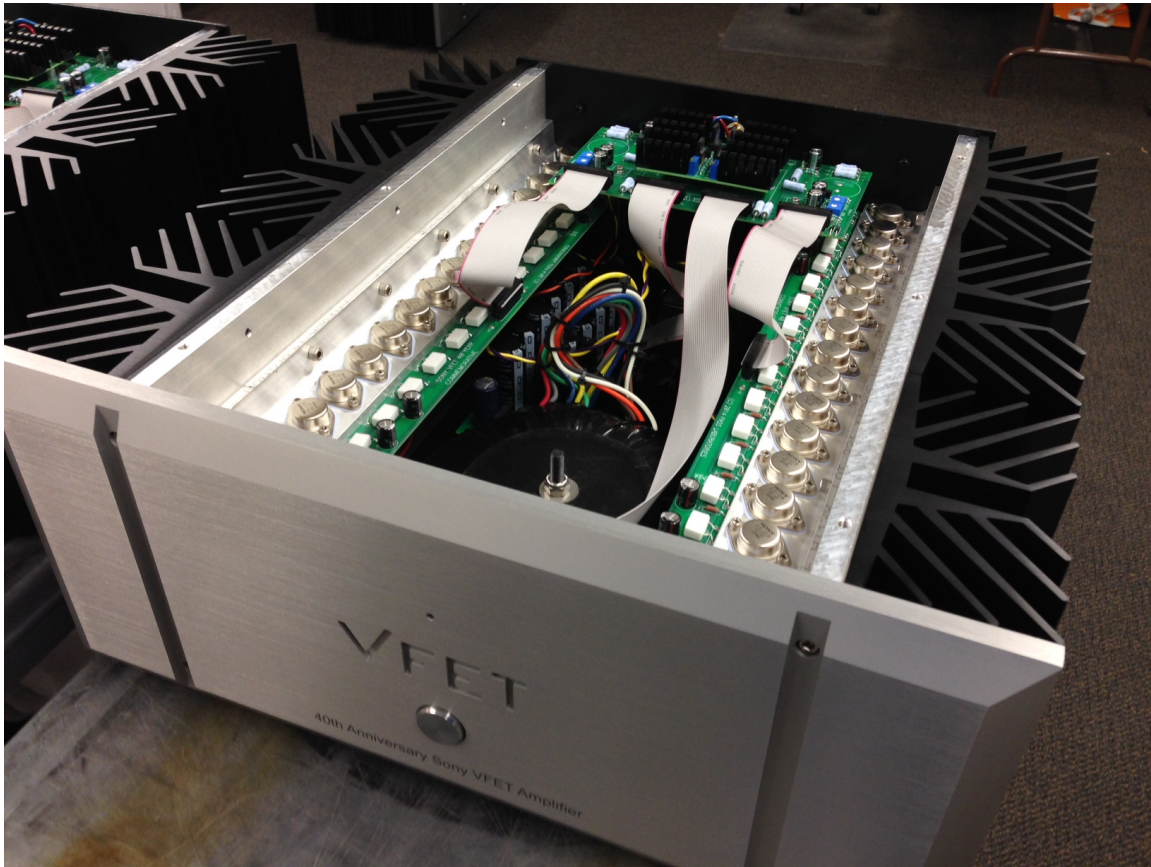


SONY VFET AMP RESPONSE

The damping factor of the amplifier comes in at 60, which is an output impedance of about 0.13 ohms. The noise is about 40 uV at 20 to 20 KHz unweighted bandwidth. The gain is switchable to 20 dB, 26 dB or 30 dB. The inputs can be operated balanced or single-ended.

We performed the final subjective tweaking of the amplifiers into the Sony AR-1 loudspeakers, and we were very satisfied – they sounded great.

Here's a picture of the final result with the top off:



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Notes:

(1) Warner, Raymond (1965). U.S. Patent #3,359,503

(2) Nishizawa et al (1972). U.S. Patent #3,828,230, "Field Effect Semiconductor Device Having An Unsaturated Triode Vacuum Tube Characteristic"

(3) Hishashi Suwa, et al (1975) "Vertical Field Effect Transistor and its Application to High Fidelity Audio Amplifiers", presented at 51st AES Convention

(4) www.thevintageknob.org (entries under Sony TAN-5550)

(5) Tadao Suzuki, "Application of Vertical FET for Pulse Width Modulation Audio Power Amplifier", presented at 55th AES Convention

(6) www.thevintageknob.org (entries under Sony TA-N88)