

## The Venerable Triode

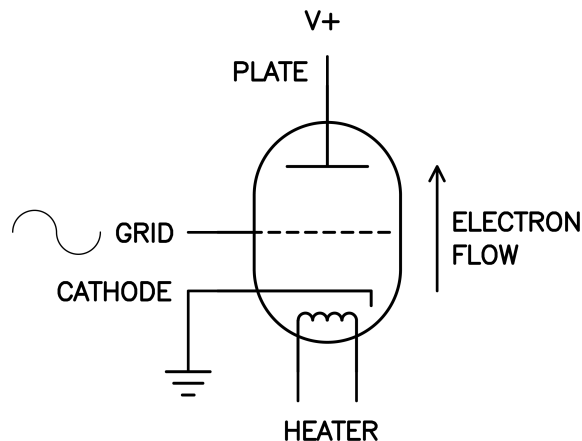
The very first gain device, the vacuum tube Triode, is still made after more than a hundred years, and while it has been largely replaced by other tubes and the many transistor types, it still remains popular in special industry and audio applications.

I have some thoughts on why the Triode remains special for audio amplifiers (apart from sentimental value) that I would like to share. But first, a quick tutorial about Triodes:

The earliest Triode was Lee De Forest's 1906 "Audion".



Over a hundred years development has resulted in many Triodes, large and small. The basic design has remained much the same. An evacuated container, usually glass, holds three signal connections, seen in the drawing as the Cathode, Grid and Plate (the Plate is also referred to as the Anode). In addition you see an internal heater, similar to a light bulb filament, which is used to heat the Cathode.

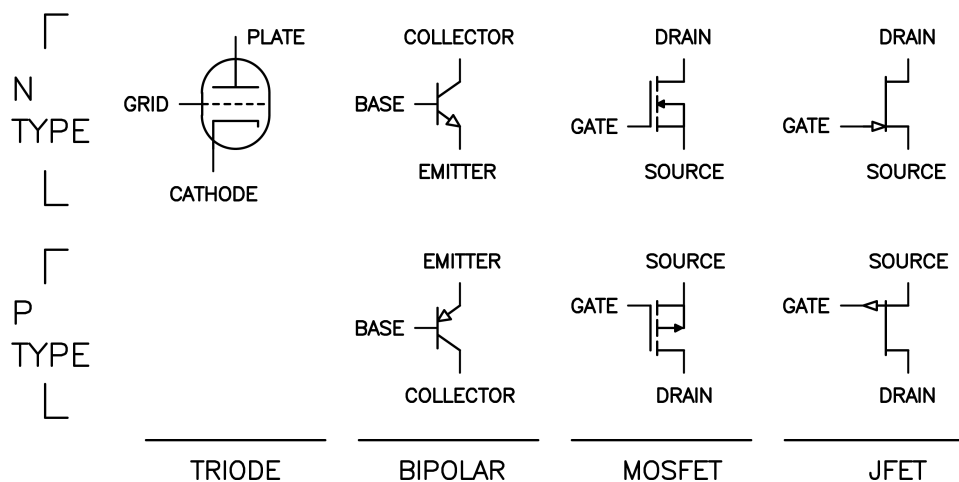


Triode operation is simple. Electrons have what's known as “negative electrostatic charge”, and it is understood that “like” charges physically repel each other while opposite charges attract. The Plate is positively charged relative to the Cathode by a battery or other voltage source, and the electrons in the Cathode are attracted to the Plate, but are prevented by a natural tendency to hang out inside the Cathode and avoid the vacuum.

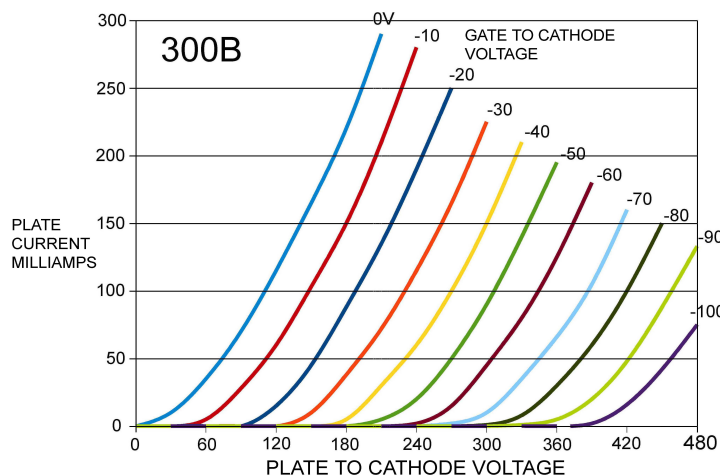
This is where the heater comes in. When you make the Cathode very hot, these electrons start jumping around, and many of them have enough energy to leave the surface of the Cathode. Once they are loose, they are free to follow their attraction to a positive charge, and so an electrical current is established from Cathode to Plate.

Gain comes from the ability to control the flow of current. The Grid is a like a charged screen which adjusts the electron's view of the voltage on the Plate. If you vary the voltage on the Grid, you vary the attraction of electrons to the Plate and so control the current going from the Cathode to Plate. As you charge the Grid negatively relative to the Cathode, less current flows. As you reduce the negative Grid charge, more current flows.

In this way you can use the Grid voltage to control the flow of electrons through the tube, and this allows large amplification of power, either as varied voltage or varied current or both. Other gain devices perform a similar trick, although the physics of their operation might be quite different. They all tend to have three connections corresponding to the Cathode, Grid and Plate but for bipolar transistors they are respectively called the Emitter, Base and Collector. For Fets these would be the Source, Gate and Drain pins.

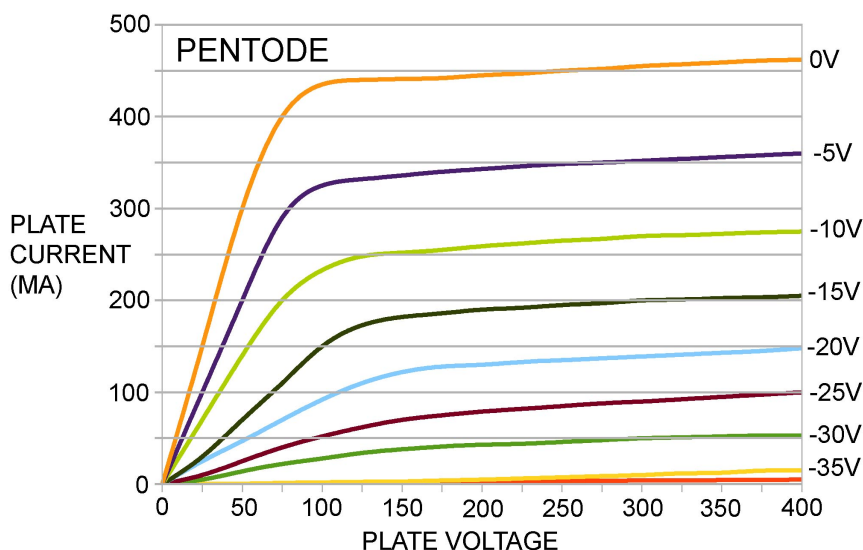


The character of gain devices is often presented as a graphic known as the characteristic curve, where the current through the device is plotted on the Y axis against the voltage across the device on the X axis for various discrete values on the control pin. For the example of a tube, we see the electron flow from Cathode to Plate versus the voltage from Plate to Cathode for different values of Grid to Cathode. Here are the curves for a 300B power Triode:



These curves show that the current from Cathode to Plate is a function not only of the Grid to Cathode voltage, but also of the Plate to Cathode. More positive Grid voltage and/or Plate voltage means more current flow. This dependence on the Plate voltage is often referred to as the “Plate impedance”

Here we see another common type of tube, one with some additional Grid pins, called a Pentode. It has a flatter set of curves, representing less dependence of current vs Plate voltage:

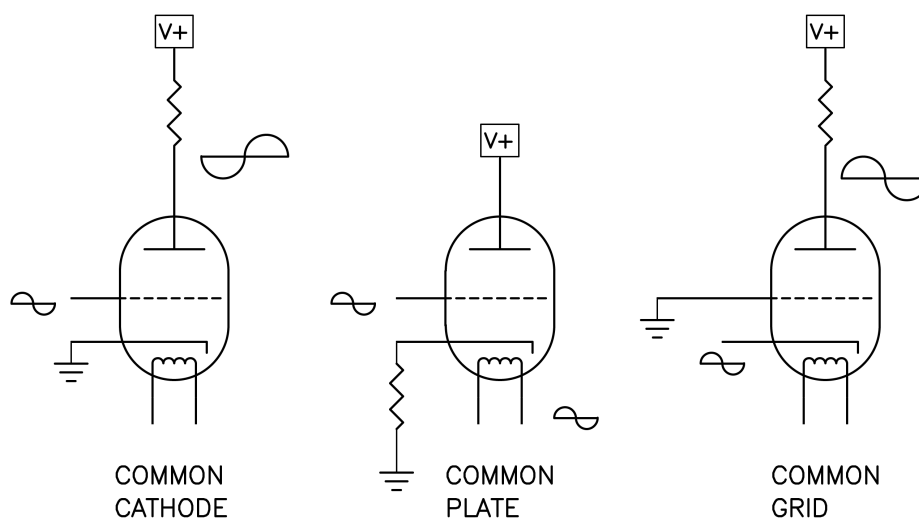


The extra control pins are used to flatten out the curves as you can see here, resulting in a higher Plate impedance for the tube, that is to say less current variation with Plate voltage. There's a specific performance advantage to this in many applications, but not in this discussion.

For other completely different types of devices there are similar characteristic curves. Jfets and Mosfets look a lot like Pentodes, but with a different range in the scales of voltage and current. The typical voltage of a transistors is lower and the current is higher - more convenient for driving loudspeakers.

A particularly unique thing about the Triode is the low Plate impedance – the dependence of current on Plate voltage. All devices, including transistors have some of this, but not nearly as much as Triodes. The exception is the rare Static Induction Transistor (SIT), also known as the VFET.

As the name implies, there are three pins to a Triode (not counting the heater, which in some designs is also the Cathode). There are three ways to use a three pin device, and for a Triode they are illustrated as follows:



In Common-Cathode mode the tube amplifies both voltage and current in response to a signal voltage on the Grid. The output appears amplified out of phase into a load at the Plate. In Common-Plate mode the Cathode output voltage follows the Grid voltage, increasing the current only, in phase without voltage gain. In Common-Grid mode the input signal current is fed into the Cathode, and the output appears on the Plate, voltage amplified in phase, but with the same amount of current as the input.

All three of these modes are very useful in amplifying signal, but each has a different quality to offer. Most of the time we see voltage gain stages with Common-Cathode, and output followers in Common-Plate mode.

These same operating modes apply to transistors, but with Fets they are Common-Source, Common-Drain and Common-Gate. With bipolar transistors we substitute the pins names with Emitter, Collector and Base.

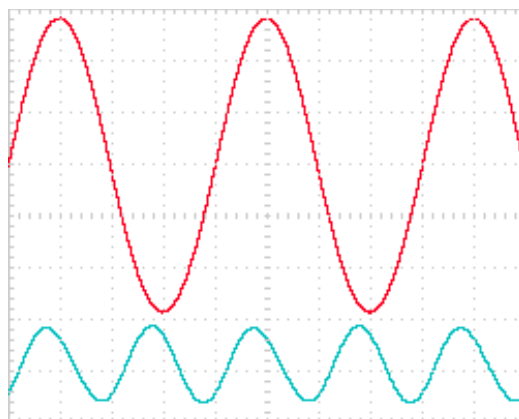
OK, end of tutorial. I told you all that stuff so that I could tell you something interesting you might not know:

Triodes are not special for audio because they are cheaper or more efficient or convenient – the opposite is the case. They are appreciated largely because their characteristic curves give rise to a sonic signature that many audiophiles want – a little second harmonic distortion. The low plate impedance of the Triode gives us some control over the amount and phase of the 2<sup>nd</sup> harmonic distortion.

The nonlinear errors found in amplifiers are routinely described as a single numerical percentage of a fundamental tone, for example “0.2% total harmonic distortion”. This number is a simplification of the series of harmonics comprising the distortion which starts with 2<sup>nd</sup> harmonic, and continues with 3<sup>rd</sup> harmonic, 4<sup>th</sup>, and so on.

It is generally agreed that lower harmonics are less annoying than higher order distortions. 2<sup>nd</sup> harmonic is the simplest, being twice the frequency of the fundamental, and the next is 3<sup>rd</sup> harmonic, three times the frequency.

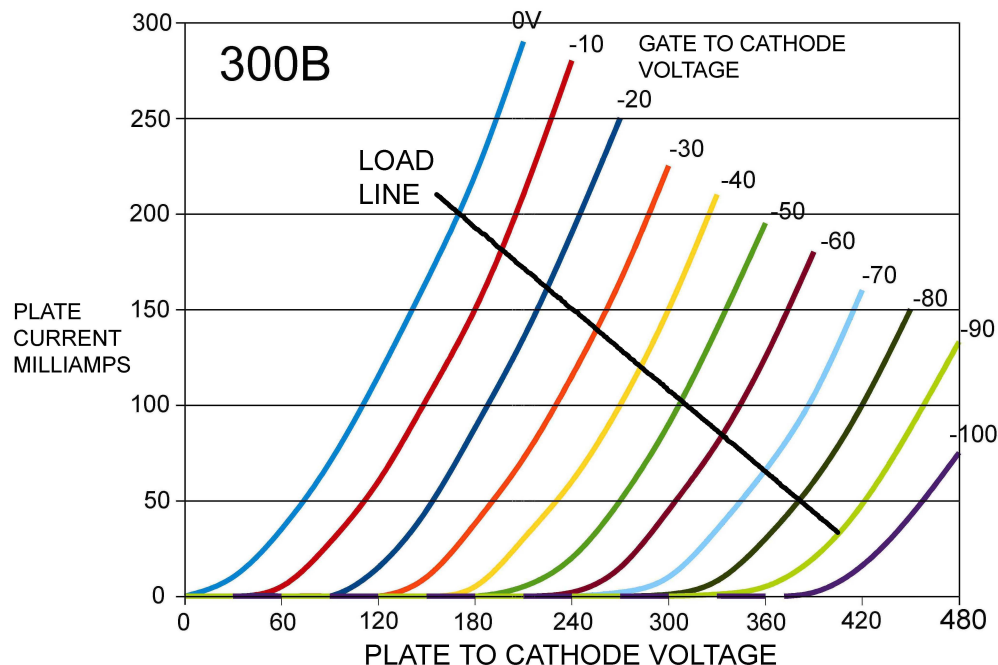
Here is an oscilloscope display showing a fundamental tone (red) and a positive phase 2<sup>nd</sup> harmonic (blue) which remains when the fundamental is removed by a distortion analyzer.



Compared to the fundamental, there are twice as many peaks and dips in the 2<sup>nd</sup> harmonic – it is at twice the frequency.

Not only is the amount of this harmonic distortion of interest, but also the phase. When harmonic waveform peaks positively at the same time as the fundamental as shown above, we will call it *positive phase*. When it is reversed and dips at the point where the fundamental is most positive, it will be called *negative phase*.

This distortion can be manipulated by selecting the operating region on the previously seen characteristic curves. In amplifying audio, the Triode moves along a load-line as seen in the example below:



In this graph, we see the load-line for 300B Triode driving about 1800 ohms. This output could be passed through an output transformer which converts it into about 4 watts into an 8 ohm loudspeaker. When the Triode amplifies musical signal, it moves around on this line – if the load is a resistor. If it is driving a speaker, or other reactive load like a capacitor or inductor, the varying impedance will make it wander around a bit.

Depending on the load impedance and the bias point, the Triode will exhibit varying levels of 2<sup>nd</sup> harmonic and also the phase polarity of that 2<sup>nd</sup> harmonic. You can have more or less of positive second, negative second.

There is a point in the middle where the 2<sup>nd</sup> harmonic disappears, leaving 3<sup>rd</sup> and perhaps some higher harmonics. This is where the measured distortion will generally be at it's lowest point, and popular with designers looking for the lowest distortion number. But not all designers are necessarily looking for the lowest number. Some want some small quantity of 2<sup>nd</sup> harmonic to “sweeten” the sound or perhaps to make it “warmer”. This is commonly understood among audiophiles, who routinely use tube preamps with solid state amplifiers to get this effect.

What is not common understood is that there is a difference in sonic signature not only in the amount of 2<sup>nd</sup> harmonic distortion, but also between positive and negative phase. This was something noticed in listening tests with *SIT* transistors. *Static Induction Transistors*, known as *VFETs* in the '70's, are Jfet devices which have a Triode-like curve. You can adjust the bias point of a SIT in a single-ended Class A amplifier and hear the difference in sound. Modest amounts of negative phase 2<sup>nd</sup> tends to create greater depth and space to the sound stage, with the illusion of better imaging. Positive phase 2<sup>nd</sup> puts the perception midrange closer, with a little more in-your-face presence.

I say this without peer-reviewed research, but I note that other experienced listeners have made similar comments in “blind” situations. I am suggesting that there likely something to this, and I encourage people to pay more attention to this aspect.

In the SIT-1 amplifier from First Watt, there is a knob on the front panel and a meter for adjusting the load-line of a single SIT transistor operated Common-Source without feedback, and the user is invited to play with it. When the knob is set counterclockwise a larger amount of negative phase 2<sup>nd</sup> harmonic is present. Somewhere near the middle, the 2<sup>nd</sup> is nulled out, leaving a trace of 3<sup>rd</sup>, and when the knob is fully clockwise, the 2<sup>nd</sup> is back again, but positive in phase.

After I got enough feedback from listeners, I adjusted the circuit so that the center-point of the meter reflected the most popular position – about 1% negative phase 2<sup>nd</sup> harmonic, and made that calibration reference for the amplifier.

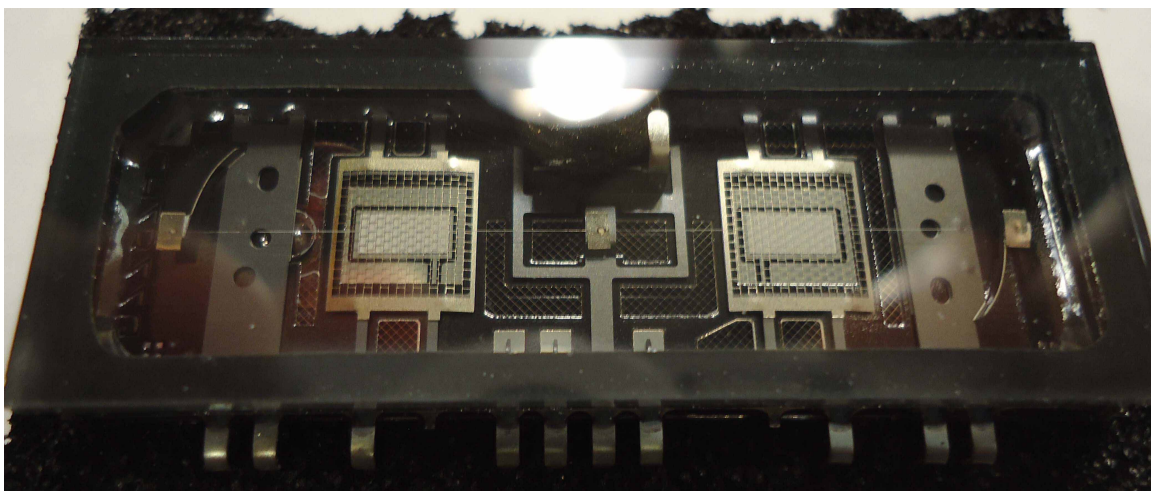
Keep in mind, that the phase of the 2<sup>nd</sup> harmonic is relative to the absolute phase of the signal. If you are using a Common-Cathode topology which inverts absolute phase, you must create a positive phase relative to the output of the circuit and then invert the phase of the signal again to restore absolute phase. Routinely this is achieved by reversing the phase of the wires to the speaker.

You can do this with all the Triodes as well, from the tiny little ECC88's to the big 211's, 300B's or 6C33C's.



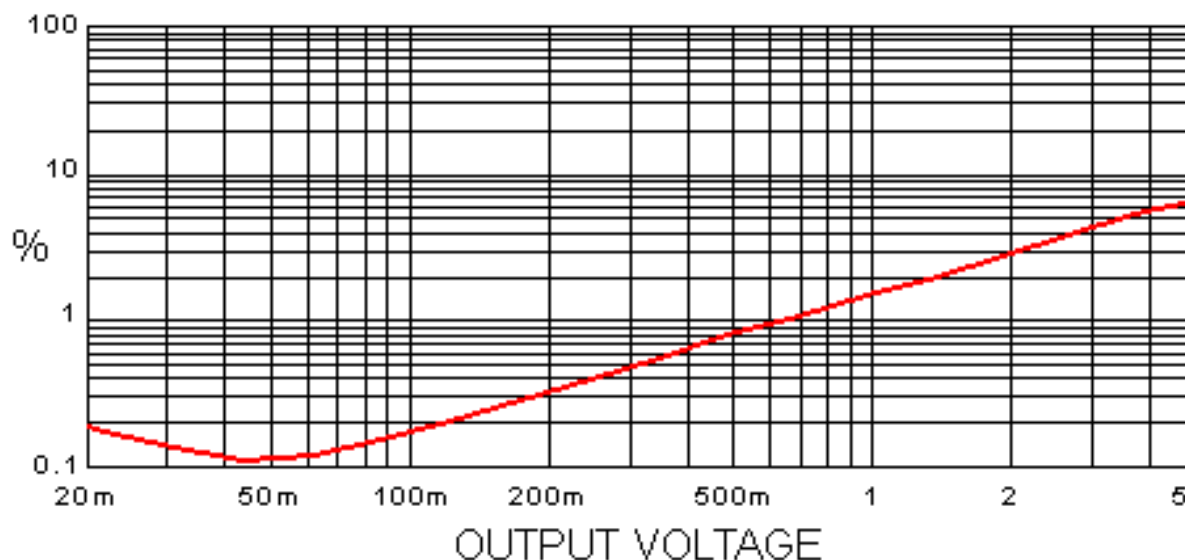
It's a simple enough trick, and if you go to the trouble of making the bias point adjustable you can listen for these effects yourself.

More recently, Korg, in association with Noritake, released a tiny dual triode for use in audio amplifiers. It looks like a glass computer chip, operating at low voltages and currents and you can see the cathode/heaters glowing at heater currents around .0017 amps. This *Nutube* is specifically designed to recreate the “Triode sound”, and it does just that.



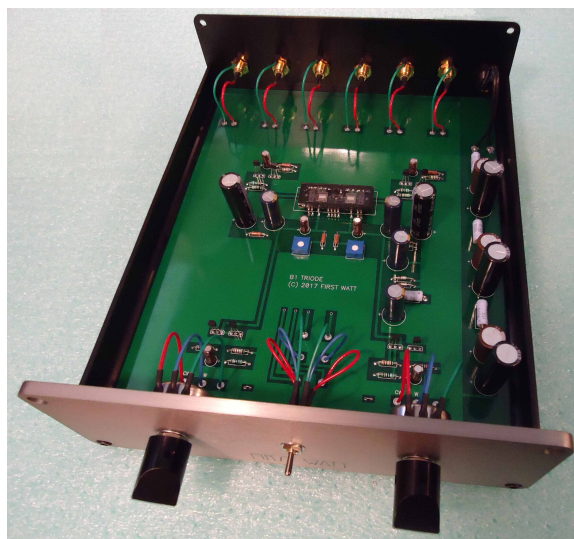


It's small, about 1 by 2 inches, and operates at power consumption of about 20 milli-Watts (including heater!). You can adjust the Grid bias point so as to create the effects I have described, and in my example Nutube circuit there is a potentiometer just for that. Here is the curve with the negative 2<sup>nd</sup> harmonic set at 1.7% at 1 volt out:



You can buy the Nutubes now for about \$50 (you only need 1 for stereo), and the evaluation schematic provided by Korg works just fine. I ran mine off of a 24 volt desktop supply with some filtering, and it delivers about 16 dB of gain.

You can see this little pre-amp using the Korg Nutube at Rocky Mountain Audio Fest this October:



Perhaps I have improved your appreciation of Triodes and sparked an interest in exploring these phenomena.

Then again, maybe not.

There are audiophiles who insist that they want to hear exactly what the artist created with alteration, *no special effects, thank you*, and that the important thing is to make the reproduction chain as neutral as possible.

Still others think that some audiophiles are delusional in their subjectivity – what they hear is the result of “sighted listening”, not their hearing acuity.

I suppose these are valid enough viewpoints.

At the same time, what we get in commercial recordings often does not retain the purity of the artist's intention – recordings are creatively “stepped on” in the process of making their way to market.

And who's to say what you can hear?

Often electronics are chosen to complement other components. Even the best loudspeakers are clearly flawed for example, as are most listening environments, not to mention individual variations in taste and hearing.

Further, the customer has the perfect right to play with the sound as he pleases.

He is, after all, paying for it.

As Joe Sammut would have said, “This is entertainment, not dialysis.”

Here's some additional reading:

The Sweet Spot      [http://www.firstwatt.com/pdf/art\\_sweet\\_spot.pdf](http://www.firstwatt.com/pdf/art_sweet_spot.pdf)

Introduction to SITs      [http://www.firstwatt.com/pdf/art\\_sit\\_intro.pdf](http://www.firstwatt.com/pdf/art_sit_intro.pdf)

Audio Distortion and Feedback      [http://www.firstwatt.com/pdf/art\\_dist\\_fdbk.pdf](http://www.firstwatt.com/pdf/art_dist_fdbk.pdf)

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