Atari Voltage Dependent Resistor (VDR) Response and Replacement Comparisons

Introduction:

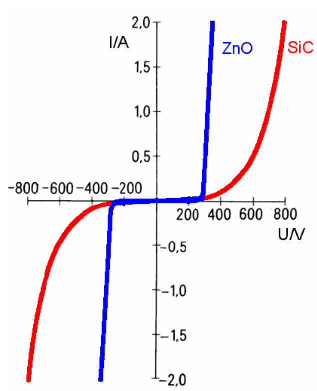
The Atari VDR (voltage dependent resistor) is an electronic component presented in an axial package that was custom made to provide a mathematical (exponential) function within an analog signal amplifier circuit. Specifically, the color vector games built by Atari between 1980 through 1983 used the VDR component to accurately compensate for the geometry of the monitor CRT while drawing vector graphics. The function of the VDR component within a simple voltage divider (the LIN trimpot is the other resistor within the divider) is to convert a linear increase in voltage into an exponential curve. This response must be specific and bi-polar in order to draw straight diagonal lines on the monitor CRT screen.

The original Atari VDR was a custom made semiconductor. It was a specially doped silicon carbide wafer with leads attached to form an axially mounted resistor. This resistor has an unusual property in that its resistance value decreases exponentially as the voltage applied across the component increases. The non-linear response of the VDR was used to create the "linearity" adjustment that allows the operator to calibrate the straightness of the diagonally drawn vectors. It also corrects the positioning and length of vectors drawn far from the center of the screen. It is thus possible to draw a grid of square blocks without them looking like rectangles. The VDR was used on the Space Duel and Tempest to Major Havoc converter boards and also on many of the game boards such as Space Duel, Black Widow, Gravitar, Major Havoc, Quantum, Star Wars, and possibly others.

VDR Fundamentals:

While there are plenty of so-called non-linear resistors available in the form of over-current and over-voltage protection devices (referred to as polyswitches, polyfuses, and MOV's), none of them lend themselves to the application of linearity adjustment. This is because they are all engineered specifically for over-voltage or over-current protection. Transient suppression is their main focus. Modern components are made from Zinc Oxide that has a very sharp turn-on response. Also, the turn-on response usually occurs at a voltage that is too high to be useful in the VDR application.

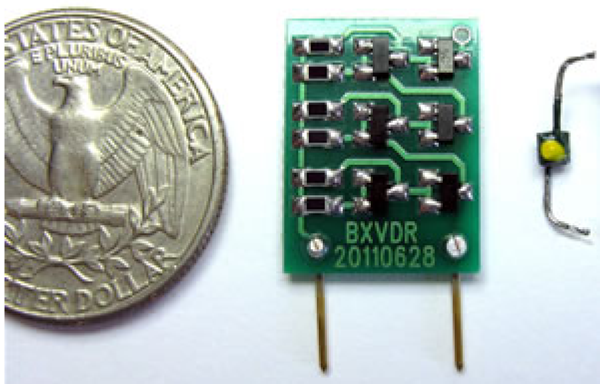
In the following picture, you can plainly see the perfect exponential response of the Silicon Carbide (SiC) material and the stark contrast in shape with respect to the Zinc Oxide (ZnO). The ideal ZnO component would not conduct at all before reaching the threshold or clamping voltage. Modern components come very close to achieving this ideal. The SiC type VDR however is required to respond across the entire voltage range within which it is used. A ZnO component simply cannot do this. The SiC component, immediately following its discovery and invention was used in analog systems to generate (as a voltage) the mathematical square of a value or to determine the mathematical root of a value. That is exactly what the LIN adjustment circuit within the Atari games is doing in order to compensate for the geometry of the CRT while drawing vectors. The ZnO based components are simply incapable of generating the same response.



VDR Replacement:

The original Atari VDR component is now very hard to come by outside of the game boards themselves. There is no modern equivalent that I am aware of. With no supply of original or equivalent VDR components available, I had to create a substitute circuit (BXVDR shown below) that provides the same resistive response as the original Atari part. The circuit is simply a resistor ladder comprised of values chosen to duplicate the exponential curve of the original VDR. Each rung of the ladder is switched on at a specific voltage by a string of simple diodes. There are 12 stages so the response of the BXVDR is actually a series of line segments drawn along the path of the original VDR response. The resolution is quite good enough to mimic the original VDR accurately.

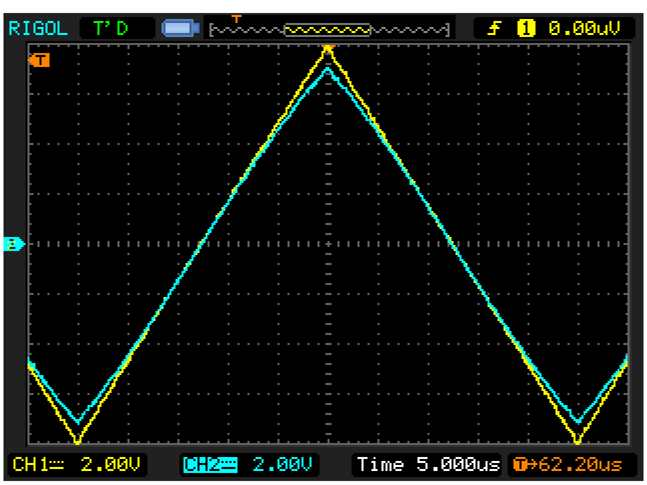
Left to right: A quarter, the BXVDR, the Atari VDR



VDR Response:

In order to visually present the response of the Atari VDR, I set up a simple amplifier with a function generator in order to drive a signal through a voltage divider comprised of a 2k resistor (value of the LIN trimpot on Atari boards) and the VDR.

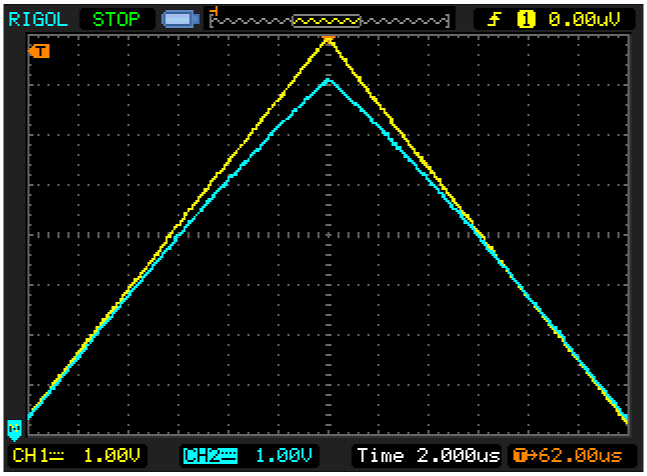
This is the response of an original Atari VDR:



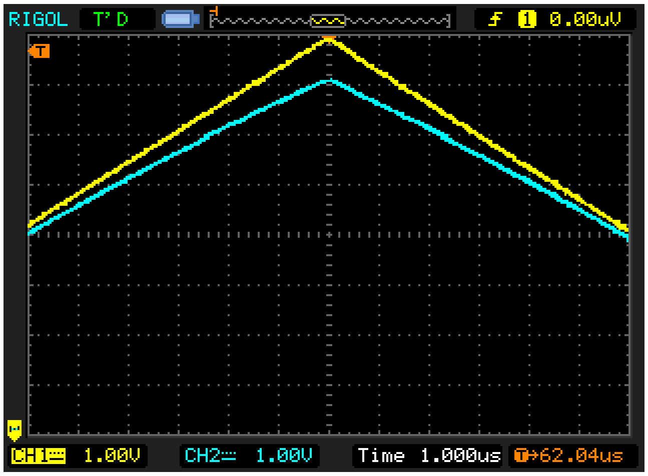
The yellow line is the input waveform, a perfect linear triangle wave. The 20 kHz signal of amplitude of +/- 8V peak is applied to the voltage divider. The blue line is the output response and it should be the same in both polarities which you can see that it is.

The difference in voltage doesn't look like much, only 1V at the top, but this represents a significant distance on the CRT screen, about an inch. Quite small changes in signal voltage are visible on the CRT screen. If you were to simply remove the VDR, a long diagonal vector would curl at the ends more and more as it approaches the outside of the CRT screen. If you replaced the VDR with a simple resistor, it would simply divide the signal down linearly and you would adjust the X/Y size pot to compensate and you'd get the same curved vector again. The exponential response (blue line) straightens those vectors out.

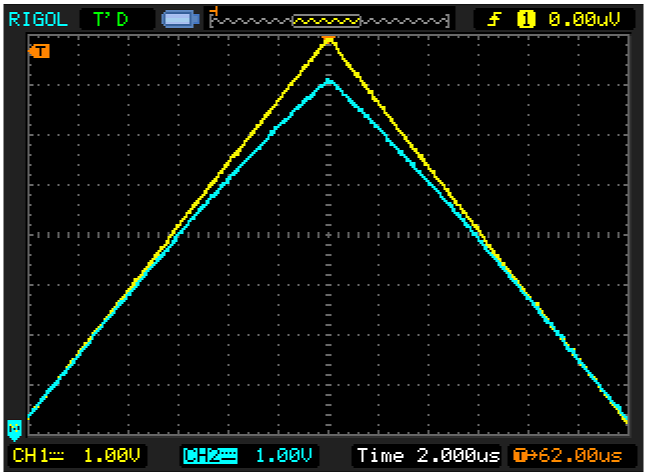
This is a little bit closer view of the original VDR response showing just the positive voltage side. The negative side is identical of course.



The picture below is the same except the timebase is wider.

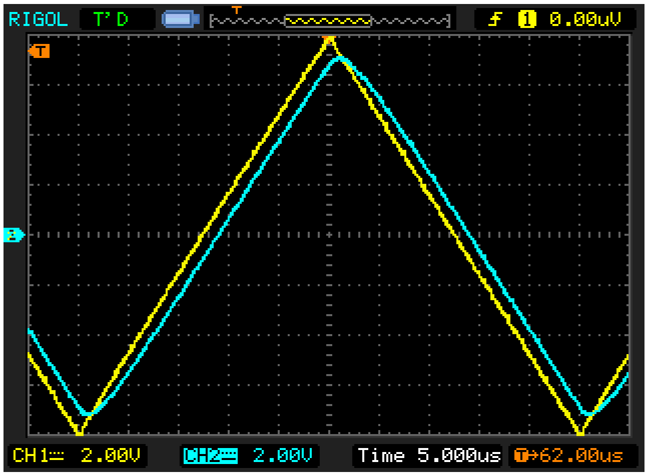


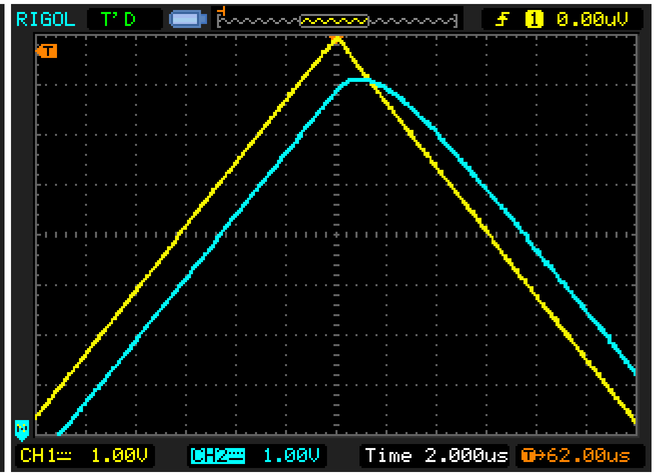
Here is the response of the BXVDR board showing the positive side only. The negative side is also identical.

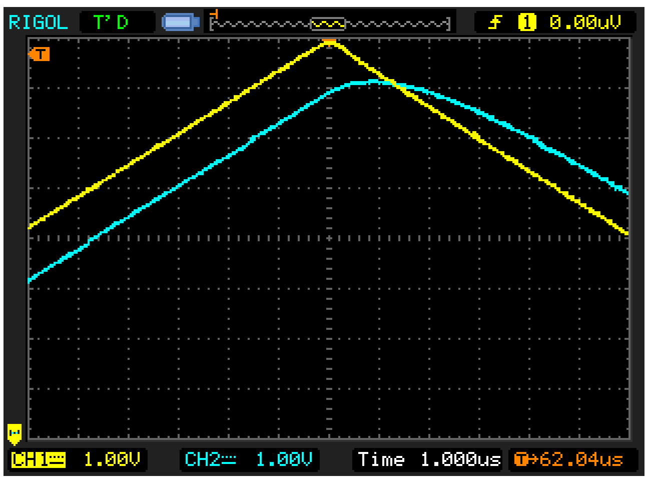


As you can see, there is no discernable difference so it can be used to replace the original Atari VDR.

It has been suggested by some that a modern MOV component can be used to replace the VDR. As I already explained previously, this is not the case. I don't expect anyone to simply take my word for it so I captured the response of one of the commonly suggested parts, the Littlefuse V12ZA05P.







With the same input signal as used with the original VDR and the BXVDR, the blue line clearly does not follow an exponential path. Worse, a large phase shift is produced. There is simply no way then that the MOV presented here can apply the correct exponential function to the vector being drawn and therefore it cannot draw a straight diagonal vector across the CRT screen. Also, this indicates that the absolute position and length of horizontal and vertical vectors will not be accurate.

In fact, the path taken while increasing in voltage is pretty much a straight line up until it reaches 6V and then it suddenly flattens. This is exactly what a MOV is designed to do but it is not what we want to see here. Also, the path heading back down doesn't recover quickly. The result is that drawing a vector in one direction would not look the same as drawing it in the opposite direction. That's bad because it shows that there's a slight hysteresis effect.

The end result of using the MOV is obvious. There would be practically no compensation since the paths of the input and output are mostly parallel. In theory, the clamping effect would limit the H or V size and create a *walling* line where vectors get crammed together into a vertical or horizontal line. Fortunately, most vector games do not draw very much so far out from the center of the screen or else this effect would be a significant problem.

Unfortunately, many people who install a MOV and then turn the LIN pot misinterpret the change in height or width of the image as an indicator that the linearity circuit is working properly. It is not. The change in overall size is a function of changing the ratio of the voltage divider itself which is exactly what the X/Y size trimpots do. This is a simple linear change in signal amplitude. It does not represent nor indicate that the overall response curve is the correct shape.