# Qualitative analysis of the responses of diodes and diode circuits to DC and AC

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**Abstract**

Diodes are polarized circuit components that provide directionality and voltage and frequency control when integrated to circuits with different arrangements. The paper aims to qualitatively analyze different waveform responses of different diode circuits to DC and AC inputs. Using resistors, capacitors, and diodes, five different circuit configurations were constructed and analyzed. For Circuit 1, an IV curve of resistor-diode circuit with a DC input was plotted to estimate the threshold voltage of the diode. For Circuits 2 to 4, the output waveform of different resistor-diode circuit configurations were recorded and compared to the input AC waveform. The comparison qualitatively analyzed the Circuits 2 to 4 to be positive shunt diode clipper, negative series diode clipper, and combination diode clipper, respectively. For Circuit 5, the ouput waveform of a diode bridge connected to a resistor and a capacitor was recorded and compared to the input AC waveform. This qualitatively analyzed Circuit 5 to be a positive diode rectifier. By analyzing different diode circuit configurations, different output waveform responses having practical applications were observed.

Keywords: diode, rectifier, DC response, AC response

## 1 Introduction

Diodes are polarized two-terminal circuit components that provide an aspect of directionality to the current flowing in a circuit. It does this by providing resistance to the circuit which if installed accordingly will either act as a wire (by providing a negligible resistance) or disconnection (by providing a very high resistance), which will permit or halt current flow, respectively, to the rest of the circuit [1].

Generally, this *asymmetric conductance* arises from the specific arrangement of the materials composing the diode: an electron-rich material (or N-type so-called from it being negative due to the abundance of electrons) in contact with an electron-poor material (or P-type derived from it being positive due to the distinct lack of electrons) creates the polarization necessary to manifest this property [1].

In practice, if a charged part of the diode (either the N-type or P-type) is connected to its corresponding opposite voltage source terminal, the charges from that part of the diode will get pulled to the direction of the voltage source terminal, preventing any flow of charges to the opposite direction through the diode, which can be seen as an increase in resistance, immediately halting the current. This is the *reverse bias*, where the diode acts as a disconnection. The opposite happens when the voltage source terminal is attached to the diode terminal of the same charge: the diode assists the flow of charges, while providing a small resistance, thus, the diode acts as a wire, as mentioned before. This small resistance in return gives an effective voltage drop of 0.7 V in common diodes. This is the *forward bias*.

Harnessing this special property, circuits with different arrangements of diodes and other components were constructed to give a variety of functions which includes control and manipulation of voltages and frequencies in AC and DC.

With this knowledge, this experiment endeavored to analyse different diode circuit arrangements and their responses to both DC and AC, and interpolate their possible large-scale applications.

## 2 Methodology

To investigate the diode's response to DC, a diode was installed in a set-up similar to a voltage divider, replacing one of the resistors (particularly the proceeding one from the point of measurement along the direction of the current) in the schematic. This is `Circuit 1`, and is the main template for the proceeding circuits.

A voltage sweep from -4 V to +4 V was performed in this circuit while noting the value of $I_{\text{diode}}$. The intermediate relationship of this variable against the input voltage $V_{\text{in}}$ were plotted to form the $IV$ curve of the diode. From this plot, approximation by intervals was implemented to estimate the experimental threshold voltage of the diode $V_{\text{thrsh, exp}}$. Data from this part were collated as `AEXP`.

To investigate the diode's response to AC, four more circuits were given for analysis - all of which were of a similar form to `Circuit 1`, except for the AC voltage source and other component modifications.

The first one, `Circuit 2`, aside from the source, has a prescribed 5V DC end voltage. On the other hand, the second one, `Circuit 3`, has the diode and resistor swapped locations (`R1` $\rightarrow$ `D3`; `D1` $\rightarrow$ `R3`).

To check their responses to AC, a 20V-1kHz sine wave was fed as the input wave for both circuits. Both output waveforms were recorded and compared to the input. Data from this part were collated as `BEXP`.

The third circuit, `Circuit 4`, has the diode replaced by a parallel network of diodes in opposite orientation, connected to the ground (`D1` $\rightarrow$ `D41`, `D42`). To check for the circuit response, the same method was executed but with different values: a 2V-1kHz sine wave was fed as the input wave, and the corresponding output wave was recorded and compared to the input wave. Data from this part were called `CEXP`.

The last circuit, `Circuit 5`, has the source connected to a network of four parallel diodes (or a *bridge*) and the diode replaced by a parallel network of a resistor and a terminal pair `C` (`D1` $\rightarrow$ `R`,`C`).

To check for the response of this circuit, different capacitors were installed in the terminal pair `C` and their corresponding responses to a 10V-60kHz sine wave were recorded and compared. The capacitors of interest were 0.33 $\mu$F, 3.3 $\mu$F, and 33 $\mu$F, and their respective output waveforms were $V_{\text{ou1}}$, $V_{\text{out2}}$, and $V_{\text{out3}}$. The output waveform of the circuit with terminal pair left open was also measured. This was labelled $V_{\text{outna}}$. Data from this part were labelled `DEXP`.

All schematic diagram of the circuits can be found in Appendix .1.

## 3 Results

From the waveforms analyzed, diode circuits are observed to substantially modify the waves that are fed in it.

For `AEXP`, two levels of approximation by intervals to estimate the voltage in joint in as seen in Figure 1 were exectued and revealed an experimental value of $V_{\text{thrsh,exp}}$ around 0.7 V, which is exactly what is expected. This value also quantises the deviation at which a general diode will act as a wire or will be forward-biased, given a directional voltage. Recall that, ideally, a diode should be forward-biased instantaneously when the voltage runs along with the orientation of the diode, which in this case when the voltage is positive and non-zero.

This deviation is observed to affect the output waveforms of the proceeding circuits.

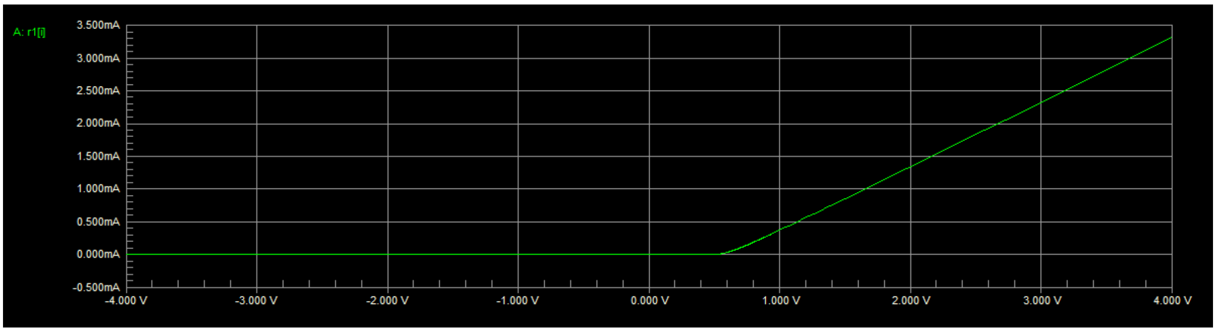


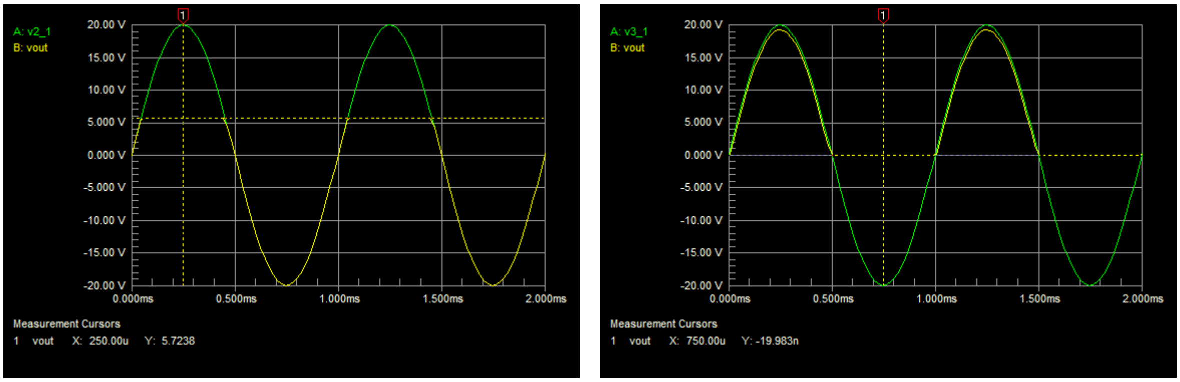

Figure 1: IV curve of the Diode in Circuit 1

For `BEXP`, the output waveforms of both circuits showed a "sliced-off" version of the input wave as shown in Figure 2. In `Circuit 2`, it was found that only the lower half of the input waveform made it through the circuit. The additional +5V DC end voltage (plus the 0.7 V diode's threshold voltage mentioned before), however, manifests as the deviation from net-zero, ie. the "sliced" part of the wave was only the part greater than +5(+0.7) V. On the other hand, `Circuit 3`, the opposite effect was seen: the lower half of the input wave was "chipped off". Additionally, since there's no connected DC end voltage, the default "slice" voltage is 0 V.

Thus, the `Circuit 2` and `Circuit 3` exhibited the responses of *diode clipper* circuits. In particular, `Circuit 2` is a *positive shunt diode clipper*, where the *positive* meant that given an end voltage, any part of the input greater than that end voltage gets clipped, as shown; and *shunt* meant that the diode is in parallel with the output connection. In contrast, `Circuit 3` is a *negative series diode clipper*, where the *negative* meant that any part of the input wave that is less than the given end voltage gets clipped; and *series* meant that the diode is in series with the output connection.

However, it should also be noted that since `Circuit 3` has no prescribed end voltage, and defaulted in clipping values over 0 V, it also shares the same response as a *negative half-wave rectifier*, a circuit that converts AC to an orientation of DC, either positive or negative, by which in this case negative. In this context, it can be seen that `Circuit 3` transforms the input wave into a periodic negative DC "pulses".

These kind of circuits can find usage in large AC circuits that require protection to specific orientation of AC.




(a) (b)

Figure 2: Input wave (green) and output waveform (yellow) from `Circuits 2` (a) and `3` (b)

For `CEXP`, the output waveform showed an ouput similar to `BEXP`, but the "slice" happens on both positive and negative sides of the input wave. In particular, the circuit "slices-off" any part of the waveform that is greater than +0.7 V and less than -0.7 V, where the value 0.7 is the same consequence of the effect seen in `AEXP`, as seen in Figure 3. Therefore, this circuit displays the responses of a *combination diode clipper*.

This kind of circuits can be used to approximate a high frequency-square wave from a sine wave. In a more practical sense, these circuit can be used to mute off any loud noises without filtering them out, since in some large-scale circuits, the volume of a sound is expressed as the amplitude of the wave which is encoded as the peak voltage of an AC.

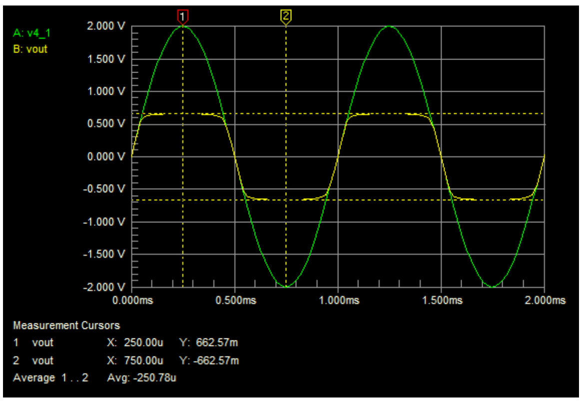



Figure 3: Input wave (green) and output waveform from `Circuit 4`

For `DEXP`, the output waveforms with all of the capacitors of interests are steady streams of positive voltages with a noticeable stabilization delay, typical to circuits with capacitors. Closer inspection reveals that a small regular fluctuation (technically called the *ripple voltage*) can be observed which diminishes as the connected capacitance is increased at the cost of slower stabilization time i.e. the time it takes to reach the maximum possible voltage or the most stable fluctuation (the numerical value of which is not calculated in this experiment). This can be visually seen in bottom graph of Figure 4, where $V_{\text{out1}}$ of the 0.33 $\mu$F capacitor showed a sharp sawtooth-like wave which stabilized first, while the $V_{\text{out3}}$ of the 33 $\mu$F capacitor showed a relatively smoother wave, but stabilized last. Thus, it can be said that the capacitor acts as a smoothing and delaying component of the output wave.

With or without the capacitor, it can be observed that the input wave. when fed to `Circuit 5`, gets locked into a purely positive wave that all the negative parts of the wave were made positive, resulting into what is essentially a pulsating DC wave with twice the frequency of the first wave. This is a response that is exhibited by *diode rectifier* circuits, particularly *positive diode rectifier*, which are basically AC to DC converters.

These circuits has found their use in management of power sources: typically found in series with a step-down transformer (usually 220-5 V) in typical device chargers.

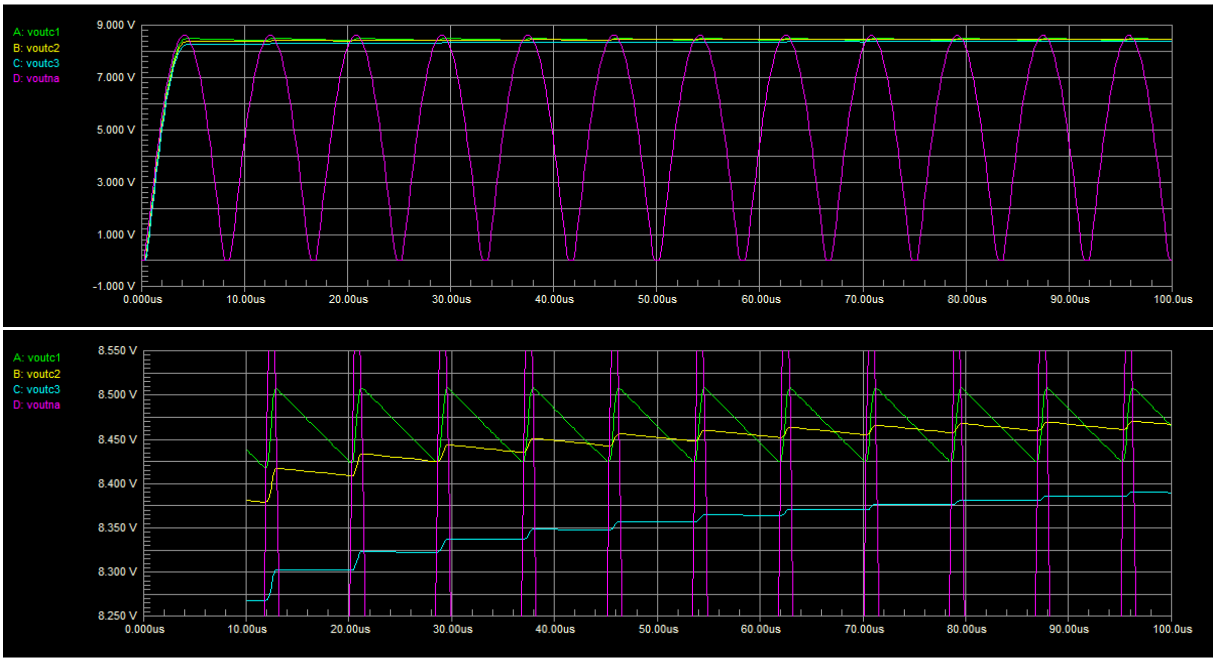



Figure 4: Output Waveform of `Circuit 4` (top) and its Ripple Voltage (bottom, zoomed)

## 4 Conclusion

In conclusion, diodes provide a practical way to manipulate inputs to circuits by an action of (but not limited to) clipping (through the use of clippers) or transformation (by rectifiers), finding a use in circuits requiring voltage regulation.

Quantitative analysis of the responses would be recommended done by observing a similar set-up and simply changing the components of a master circuit, which is the `Circuit 1` in this case, and feeding them all the same input wave. In such set-up, responses of circuits can be directly compared from one circuit to another, providing an easy parameter control for any possible statistical analysis.

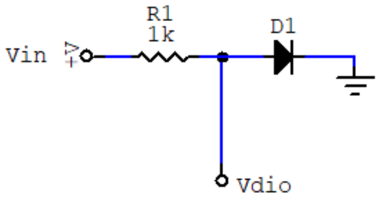
## References

[1] N. Storey, *Electronics: A Systems Approach* (Pearson, New York, 2017).

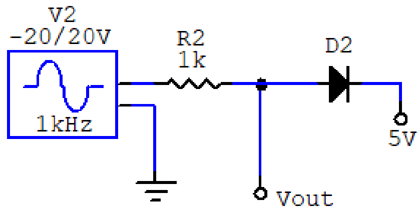
[2] J. D. Irwin and R. M. Nelms, *Basic Engineering Circuit Analysis, 11e* (John Wiley & Sons Inc., USA, 2015).

# Appendix

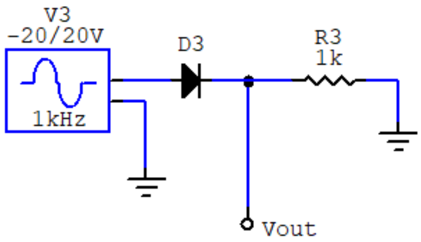
## .1 Schematic Diagrams of the Circuits used



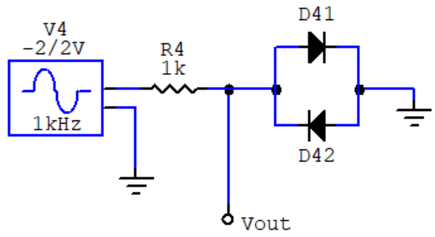

(a) `Circuit 1`



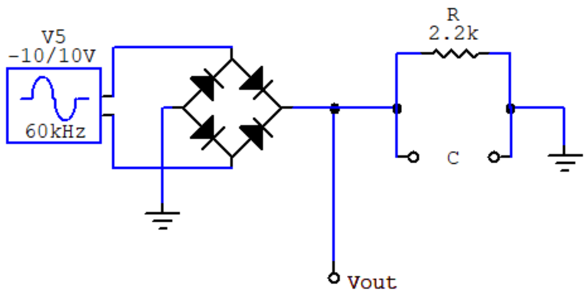

(b) `Circuit 2`




(c) `Circuit 3`




(d) `Circuit 4`




(e) `Circuit 5`

Figure 5: Schematics of the Circuits of Interest