De Silva, CK
Geraldez, Lyle Kenneth
[AppPhysics 181]: Activity 7: OpAmps-II

Objectives

1. To observe the manifestation of slew rates and their implications.
2. To observe the responses of OpAmps from their interactions with capacitors and diodes in circuits harnessing their combined properties for wave transformations.

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Solution Proper

Limitation: Slew Rate

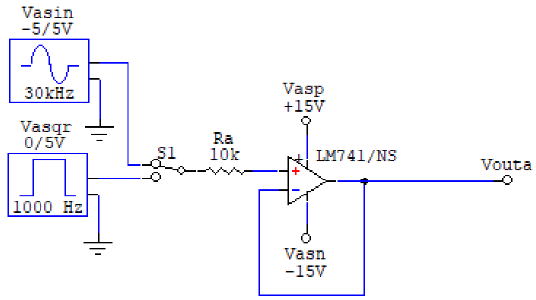
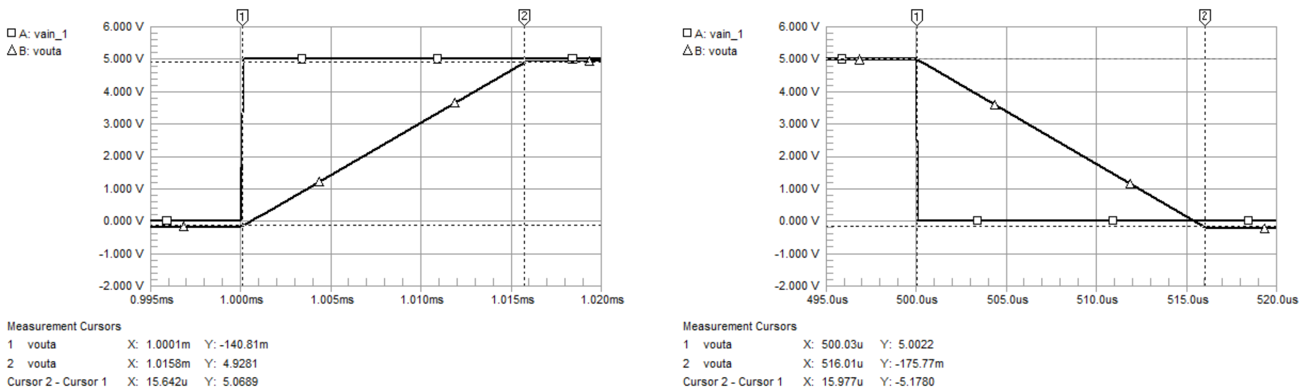


Figure 1: Schematic Diagram of Circuit A



(a) (b)

Figure 2: Positive (2a) and Negative (2b) Slew Slopes of `LM741` as measured in Circuit A, with `S1` toggled to `Vsqr`

To measure the slew rate of `LM741` OpAmp, the average of the absolute values of the slew slopes shown in Figure 2 were calculated as shown below. The experimental value turns out to deviate from the theoretical by 36%, indicating the possiblity that the opamp used might actually be an `LM741A`.

$$
\begin{aligned}
+\mathrm{SR} &= \left|\frac{\Delta\texttt{Vouta}}{\Delta t}\right| \\
&= \left|\frac{-140.81_{\mathrm{E}-3} - 4.9281}{1.00001_{\mathrm{E}-3} - 1.0158_{\mathrm{E}-3}}\frac{[\mathrm{V}]}{[\mathrm{s}]}\right| \\
&= \left|\frac{5.069\ [\mathrm{V}]}{15.7_{\mathrm{E}-6}\ [\mathrm{s}]}\cdot\right| = \left|\frac{5.069\ [\mathrm{V}]}{15.7\ [\mu\mathrm{s}]}\right| \\
&= 0.3228\left[\frac{\mathrm{V}}{\mu\mathrm{s}}\right]
\end{aligned}
$$

$$
\begin{aligned}
-\mathrm{SR} &= \left|\frac{\Delta\texttt{Vouta}}{\Delta t}\right| \\
&= \left|\frac{5.0022 - (-175.77_{\mathrm{E}-6})}{500.03_{\mathrm{E}-6} - 516.01_{\mathrm{E}-6}}\frac{[\mathrm{V}]}{[\mathrm{s}]}\right| \\
&= \left|\frac{5.022\ [\mathrm{V}]}{15.98_{\mathrm{E}-6}\ [\mathrm{s}]}\right| = \left|\frac{5.022\ [\mathrm{V}]}{15.98\ [\mu\mathrm{s}]}\right| \\
&= 0.3143\left[\frac{\mathrm{V}}{\mu\mathrm{s}}\right]
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{SR}_{\mathrm{ave}} &= \frac{0.3228 + 0.3143}{2}\left[\frac{\mathrm{V}}{\mu\mathrm{s}}\right] \\
&= 0.3186\left[\frac{\mathrm{V}}{\mu\mathrm{s}}\right]
\end{aligned}
$$

$$
\begin{aligned}
\%\Delta_{\mathrm{SR}} &= \frac{0.5 - 0.3186}{0.5}\% \\
&= (1 - 0.6372)\% \\
&\sim 36\%
\end{aligned}
$$

Flipping the switch to `Vasin`, the frequency of the 5V sine wave was allowed to change. Given that, the peak amplitude of the output wave started to noticeably deviate around 11 kHz and quite significantly around 20kHz. If we proceed with the assumption that the OpAmp is a `LM741A`, dividing 345000 (the slew rate in $\frac{\mathrm{V}}{\mathrm{s}}$) by the product of 11kHz and 5V (peak voltage) gives a value of approximately 2π ($6.272 \sim 2(3.136)$). This is an informal derivation using scaling analysis.

By observation, the slew rate, having units of voltage per time, indicates the maximum driving input that can be fed into the amplifier that upon which beyond that point, the frequency and/or voltage can suffer.

Reference Sheet

1. LM741 (Information Sheet). https://www.mit.edu/ 6.301/LM741.pdf

Application 1: Integrator OpAmps

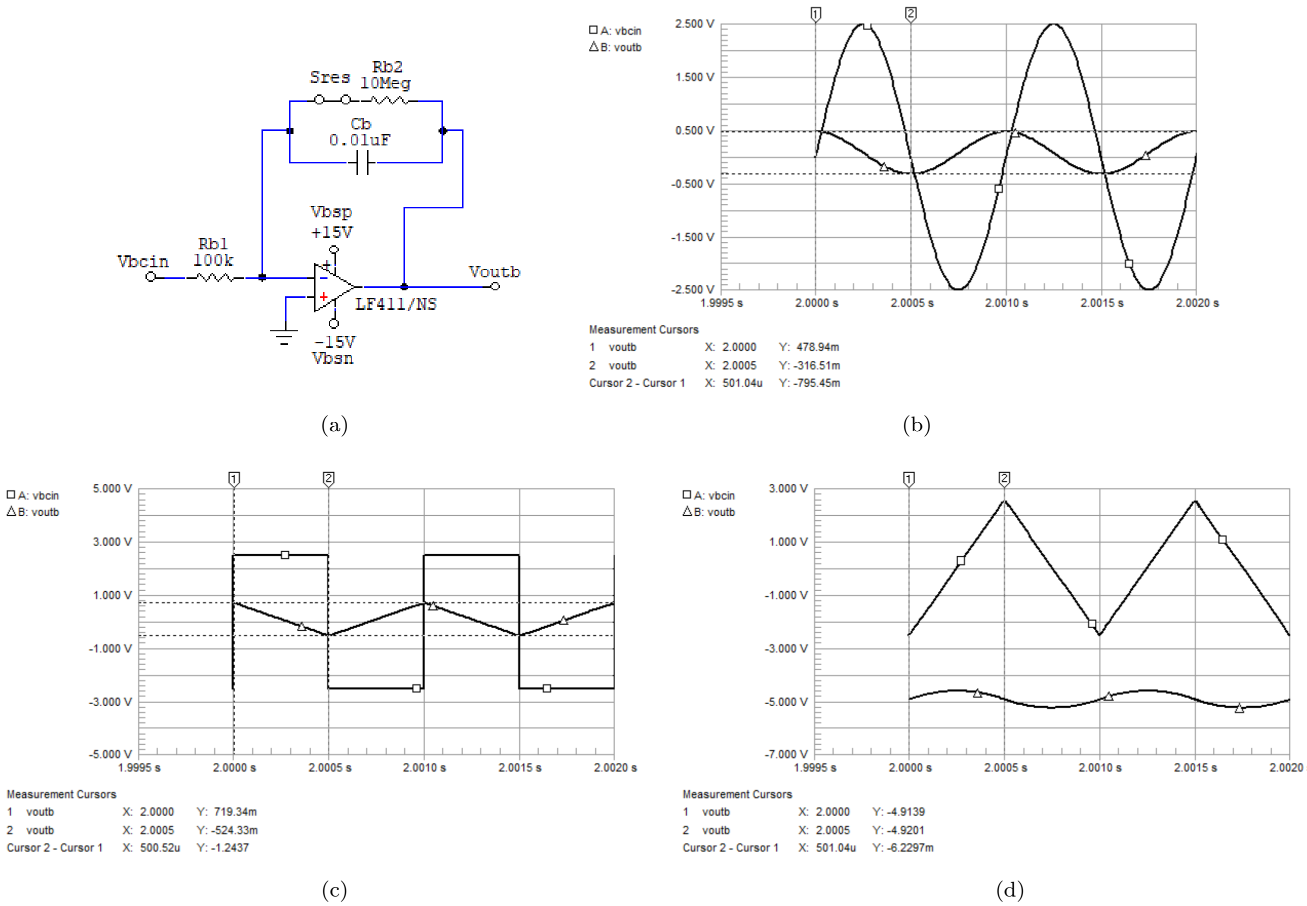


Figure 3: Schematic (3a), Input and Output Waveforms for Circuit B [(b), (c), (d)] measured 2 seconds after input

The circuit is an **OpAmp Integrator**, so-called for the its integration effect as seen in Figure 3. Since basically the output voltage is $v_o = \frac{1}{\texttt{Rb1}\cdot\texttt{Cb}}\int_0^t v_{in}\, dt$, the voltage gain should be $\frac{1}{\texttt{Rb1}\cdot\texttt{Cb}} = \frac{1}{1_E 3} = 1000$, which is clearly not observed in the plots. Additionally, a "vertical" shift can be noticed in all of the output plots, indicating an emerging DC offset.

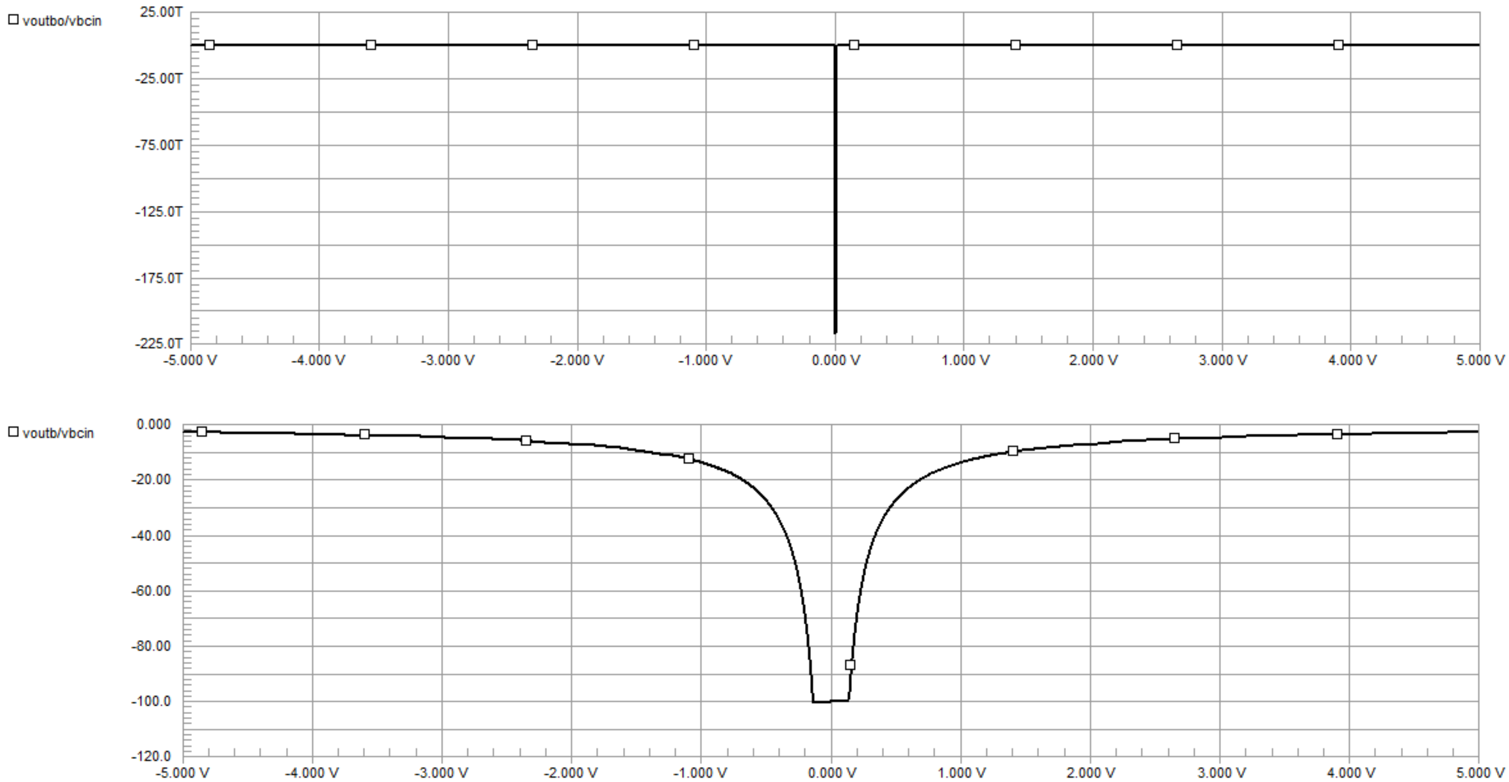


Figure 4: Voltage Gain in Circuit B

The function of the 10MΩ resistor is to fix the infinite-gain problem when the input voltage is 0 V. As shown in Figure 4, the sharp dip to infinity becomes shallower and more importantly, finite.

Reference Sheet

1. LF411 (Information Sheet). https://www.egr.msu.edu/ wierzba/LF411.pdf

Application 2: Differentiator OpAmps

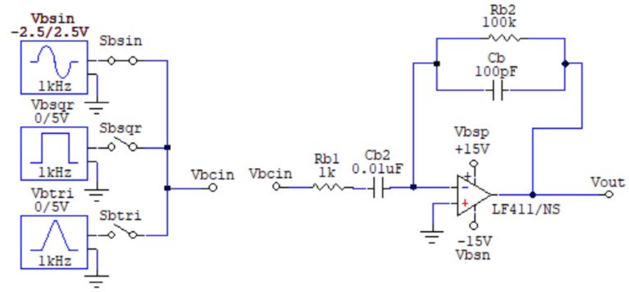


Figure 5: Schematic Diagram of Circuit C

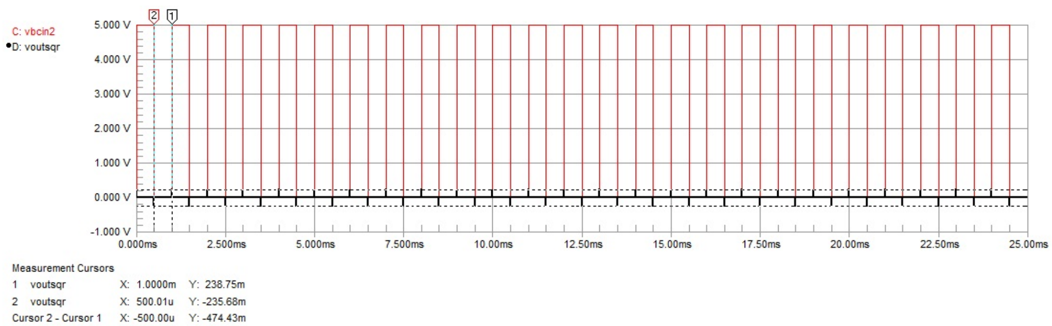


Figure 6: Output waveform (black lines) of differentiated square wave input (red lines)

Figure 6 shows the differentiation of the square wave input with $V_{pp} = 5$ V, $f = 5$ kHz. The output waveform are spikes, as expected, having an amplitude of $V_{pp} = 475$ mV.

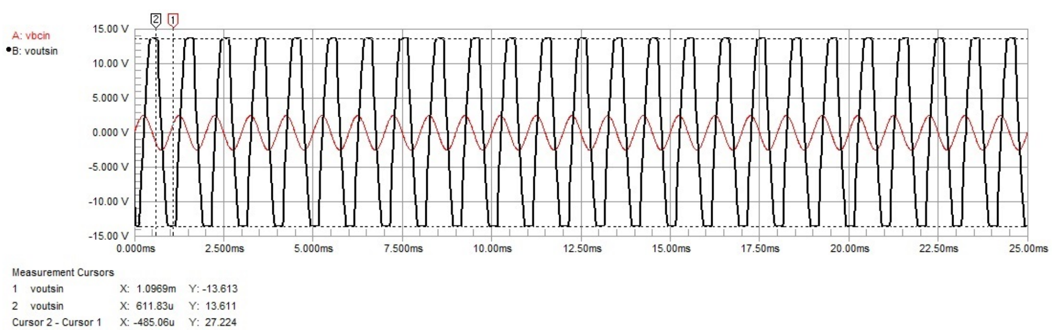


Figure 7: Output waveform (black lines) of differentiated sine wave input (red lines)

Figure 7 shows the differentiation of the sine wave input with $V_{pp} = 5$ V, $f = 5$ kHz. The output waveform is a phase-shifted sine wave (cosine wave), as expected, having an amplitude of $V_{pp} = 27.2$ V.

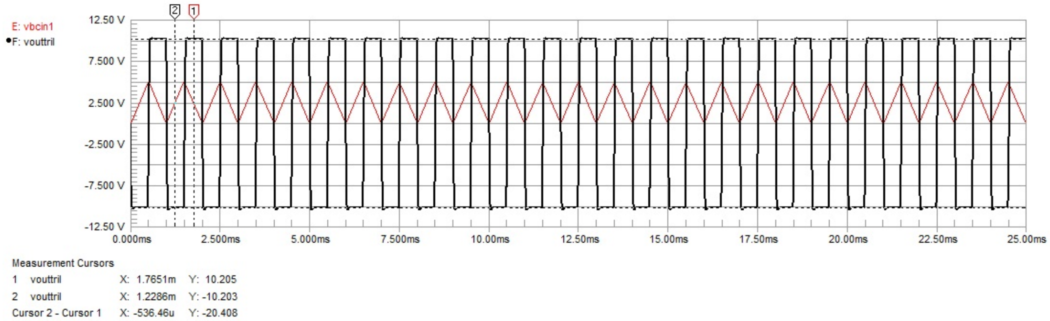


Figure 8: Output waveform (black lines) of differentiated triangle wave input (red lines)

Figure 8 shows the differentiation of the triangle wave input with $V_{pp} = 5$ V, $f = 5$ kHz. The output waveform is a square wave, as expected, having an amplitude of $V_{pp} = 20.4$ V.

Application 3: Rectifier OpAmps

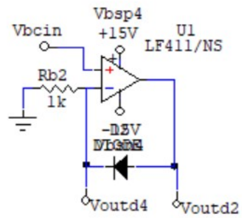


Figure 9: Schematic Diagram of Circuit D

Figure 10: Input waveform (blue line) and output waveform (black line) Of Circuit D at `Voutd2`

Figure 10 shows the rectification of the square wave input with $V_{pp} = 5$ V, $f = 5$ kHz measured at `Voutd2`. Observe that at some points, the waveform looks slanted, opposing to the expected straight line from a square wave. Hence, it is considered to be "glitched". This is due to the slew-rate limitations of the op-amp allowing small glitches as the input reaches the clamp voltage.

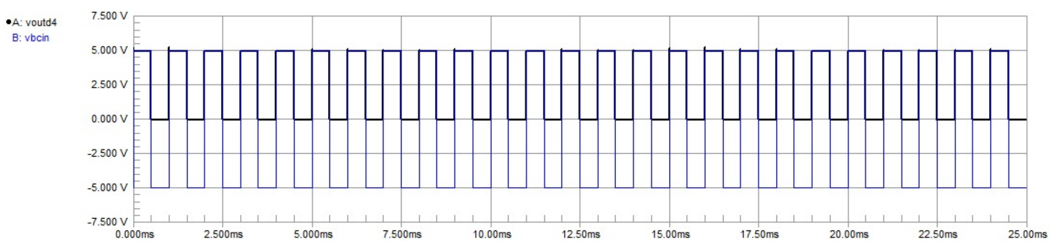


Figure 11: Input waveform (blue line) and output waveform (black line) Of Circuit D at `Voutd4`

Figure 11 shows the rectification of the square wave input with $V_{pp} = 5$ V, $f = 5$ kHz measured at `Voutd4`. The rectifier op amp circuit properly executed a successful rectification of the input wave. In the positive half-cycle of the operation, the output waveform is similar in shape and in amplitude to the input waveform. In the negative half-cycle of the operation, the output waveform is fixed at 0 V.

Application 4: Clamp OpAmps

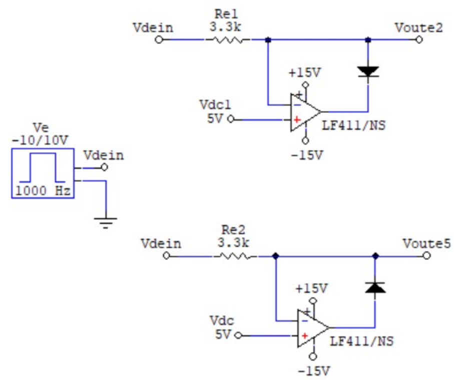


Figure 12: Schematic Diagram of Circuit E

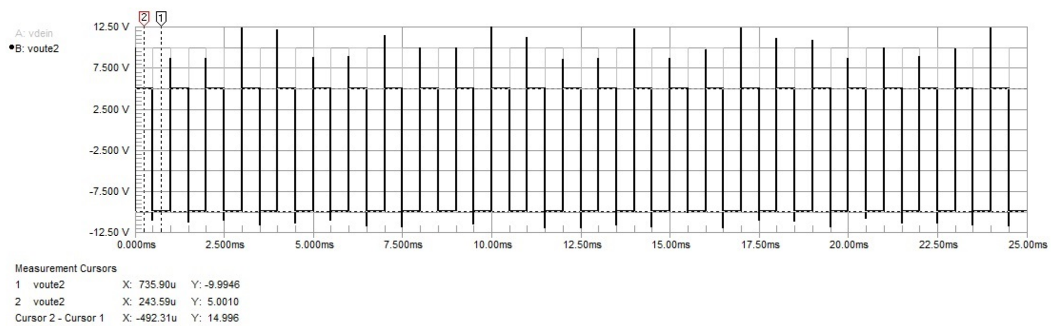


Figure 13: Input waveform (lighter lines) and output waveform (darker lines) at `Voute2` of Circuit E

As shown in Figure 13, output waveform is an inverted (180°-shifted) and scaled version of the input waveform. Both input and output waveform share the same minimum voltage at -10V. However, the maximum voltage of the output waveform is clamped at 5V.

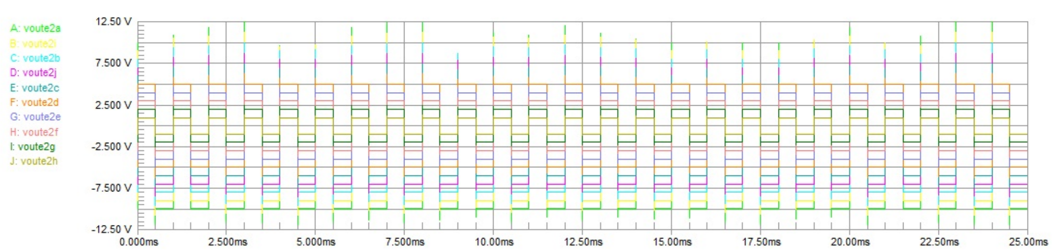


Figure 14: Output waveform of different input voltages from 10V to 1V downwards with 1V increment

It can be observed from Figure 14 that as you decrease the input voltage, the output's maximum voltage remains clamped at 5V while the minimum voltage is equal to the decreasing input voltage. This continues up until the input voltage reaches 5V. From here on, both maximum and minimum is equal to the input voltage. Below 5V, the output waveform is the same as the input waveform.

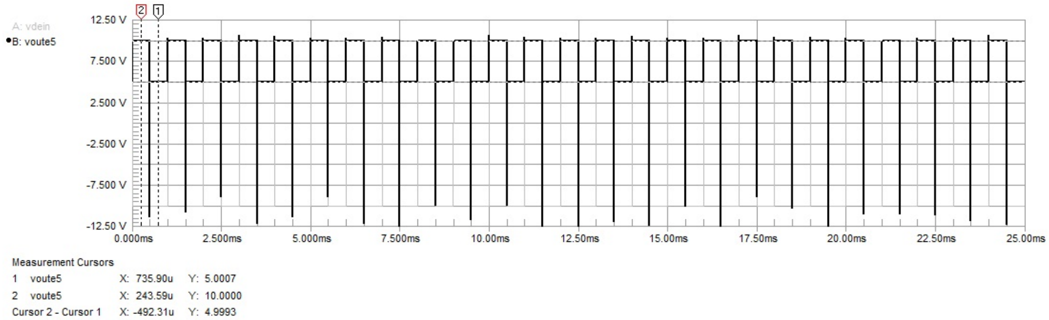


Figure 15: Input waveform (lighter lines) and output waveform (darker lines) at `Voute5` of Circuit E

Reversing the direction of the diode, the input and output waveform now shares the same maximum voltage at 10V. However, the minimum voltage of the output waveform is clamped at 5V.