AN68

SiC Half-bridge Integrated Power Module Dual-sided Output

HALF-BRIDGE MODULES AND PWM - WHAT COMES TO MIND?

The half-bridge module that is used in this application is commonly used in PWM circuits. Half-bridge switching modules (pulse width modulation), also referred to as Class D output, are recognized for their high efficiency when used as an amplifier and compared to other classes of amplifier output stages like Class A, A/B and C, which dissipate more power.

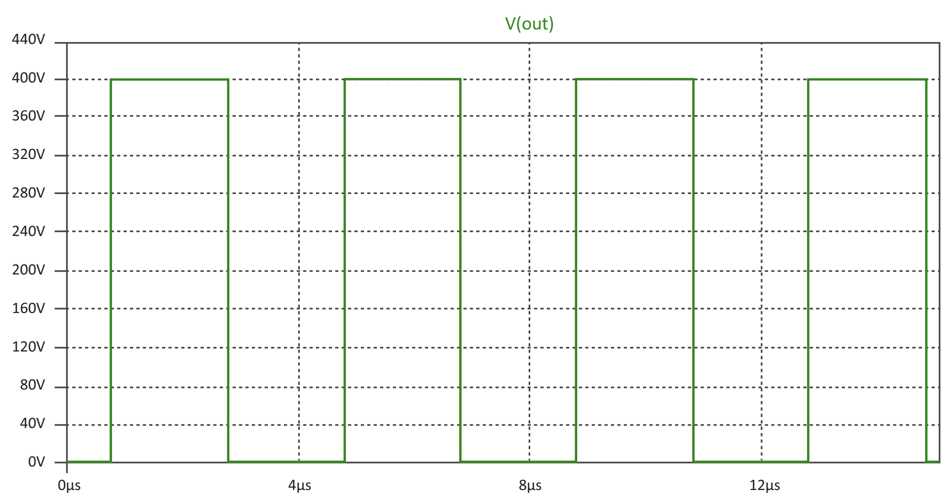
When thinking of Class D output stage operation, an image forms in the mind of an output that switches between ground and the positive voltage rail continuously, usually with some modulated pulse width. This type of output behavior and efficiency lends itself to a multitude of applications including motor drive as well as piezo drive. These application types have many variations of operating conditions to satisfy. To that end, it would be interesting to explore some non-traditional uses of the switching output products that are being utilized in such applications.

One of those non-traditional uses will be explained herein. The technique that is discussed in this application note will have to do with how to bias the circuit for a half-bridge switching module to be able to swing, not only from 0V/ground to the positive voltage rail, but from the negative voltage rail to the positive voltage rail, effectively making the output able to swing dual-sided, both positively and negatively, with respect to the 0V line. The intent of this application note will be to focus on the biasing scheme regarding half-bridge switching module low side and high side supply voltages as well as the input logic signals and their reference and will not get into associated control schemes. To help illustrate the differences between a traditional single-sided output half-bridge bias circuit and the technique that will be described in this application note, the bias scheme for a single-sided output half-bridge circuit will be detailed.

SINGLE-SIDED OUTPUT HALF-BRIDGE MODULE BIAS CIRCUIT ARCHITECTURE

As mentioned above, traditional half-bridge switching output will swing from 0V/ground to whatever voltage the positive voltage rail is set to, within specified maximums. This means that, when configured with the negative V_S pin grounded, as is common practice, half-bridge switching output is limited to positive voltage swing as is shown in *Figure 1*.

Figure 1: Single-sided Output Simulation Results

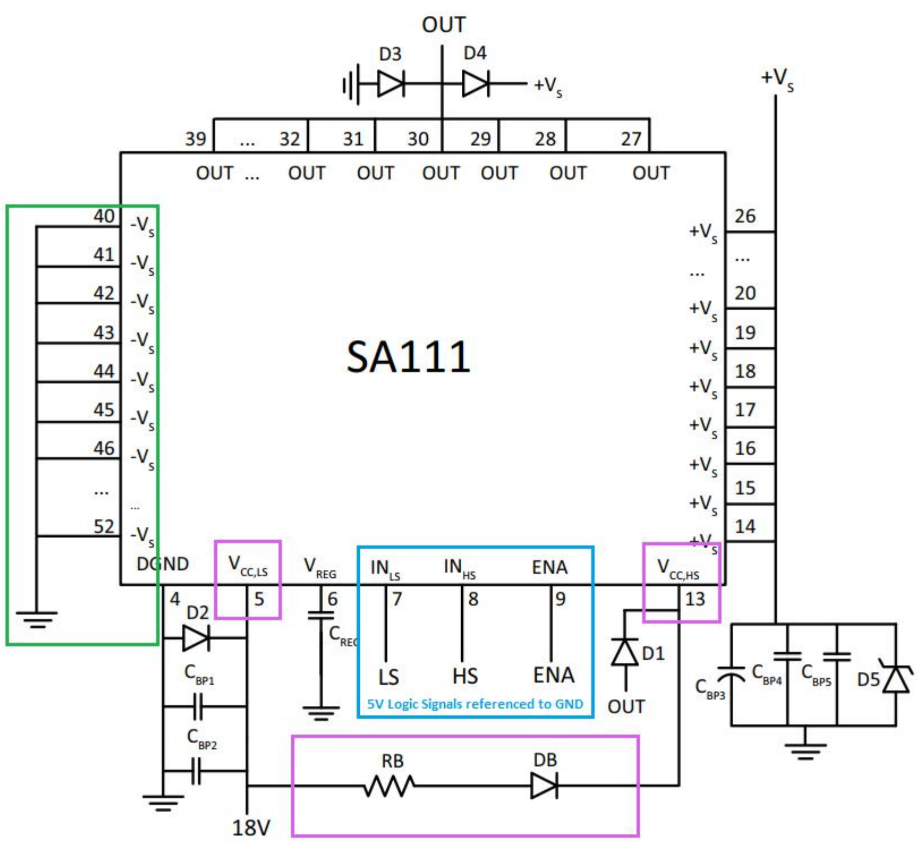


The output of the half-bridge module switches continuously from 0V to the positive voltage rail setting, which is 400V in this case, at a specified frequency and duty cycle. CAUTION: High voltages can be dangerous to work with and around. Maximum caution should be exercised at all times when circuits are powered on. To get a sense of all the circuit elements required to bias a half-bridge module for single-sided output swing, an example circuit can be referenced. In this instance, the reference circuit for the Apex SA111 will be shown since it will be used as the vehicle to illustrate this application.

The SA111 is a fully integrated half bridge module based on Silicon Carbide technology. The half bridge provides up to 32 A continuous output current and a maximum supply voltage of 650V under microcontroller or DSP control. These features make the device very attractive for use in a wide array of applications such as power conversion, motor control and class D amplification. Due to its internal circuit topology, the SA111 operation is illustrated in its data sheet for uni-polar output (single-sided) voltage levels referenced to ground. All input logic signals are ground referenced as well. This application note presents a circuit implementation which allows the SA111 to provide bipolar output (dual-sided) voltage levels with respect to ground.

When the diagram in *Figure 2* is examined, there are multiple areas identified that denote circuit elements that are different when comparing single-sided output configuration to dual-sided output configuration. For single-sided operation, the negative supply($-V_S$) pins 40 through 52 are all tied to ground. This ground potential acts as a reference for the control logic signal inputs (ENA, IN_{LS} and IN_{HS}) which are limited to logic voltage levels between 2.5V and 5V. When in single-sided output configuration with the $-V_S$ pin(s) connected to ground, this allows for the simplicity of supplying logic signals within the range of 2.5V to 5V that are referenced to 0V/ground.

Figure 2: Single-sided Output Circuit Diagram



These kinds of logic voltage levels can be realized through low power control devices like µC's, which are generally part of the larger control scheme for a PWM circuit. $V_{CC,LS}$ and $V_{CC,HS}$ voltages are also necessary for proper function of a silicon carbide FET based switching module output stage. In the *Figure 2* diagram, there is a network shown between the $V_{CC,LS}$ and $V_{CC,HS}$ pins that consists of components R_B and D_B. This resistor and diode combination form a bootstrap network that provides a level shifted voltage to the $V_{cc,HS}$ pin that is referenced to the output of the half-bridge switching module. This bootstrap network is suitable for level shifting as long as the output swing remains single-sided. *Figure 2* will be referenced again later in the document in comparison to dual-sided output configuration.

SWITCHING OUTPUT HALLMARKS

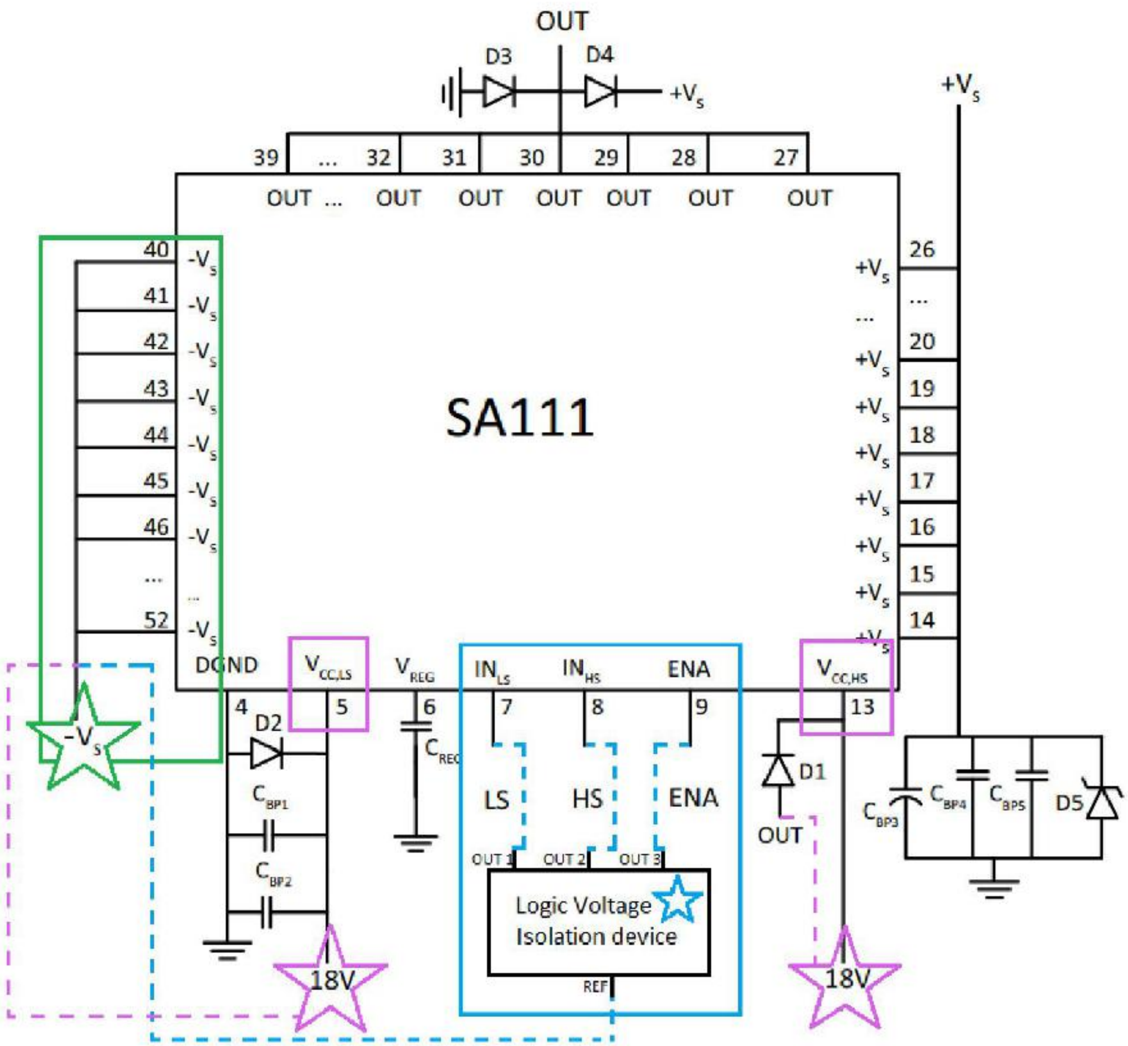
Half-bridge switching modules, like the Apex SA111, are sought after because of their decreased power dissipation in the output stage compared to non-switching amplifiers. Since the output stage is constantly switching back and forth, the difference between V_{SUPPLY} and V_{OUTPUT} is kept to a minimal level that generates much less heat than an output with FET's that can have large magnitude differences between V_{SUPPLY} and V_{OUTPUT} while their output can be anywhere between the +/- $V_{SUPPLIES}$, like Class A and A/B. The same switching functionality that creates the efficiency behind utilizing switching output is also the reason that switching modules are sometimes excluded from certain applications that require low noise. Switching module architecture has inherent noise, related to the continuous switching activity of the output, which does not exist in non-switching amplifiers.

These traits make switching modules suitable for high power motor drive applications that are not sensitive to noise but require high efficiency. With the abundance of motor drive applications throughout the various industrial, medical and technological market sectors, expanding the use cases for switching modules with the technique discussed in this application note is a laudable goal. Switching modules have even found use amongst piezo devices with one notable example being sonar applications.

DUAL-SIDED OUTPUT HALF-BRIDGE MODULE BIAS CIRCUIT ARCHITECTURE

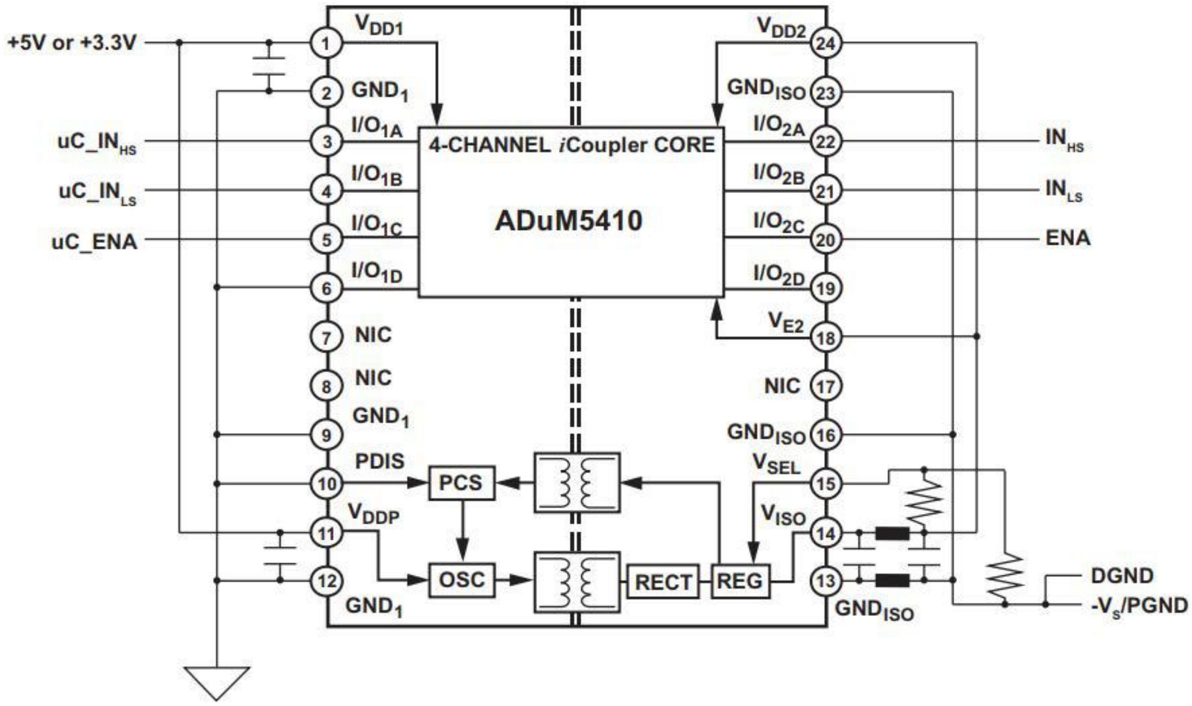
Along with the ability for the output of the half-bridge switching module to swing dual-sided with respect to 0V, there are some considerations that must be taken in to account with regard to the areas of interest that were mentioned in the description of the single-sided output biasing scheme. In *Figure 3* there are stars placed to point out the areas of the biasing circuit that have been changed with respect to *Figure 2*.

Figure 3: Dual-sided Output Circuit Diagram



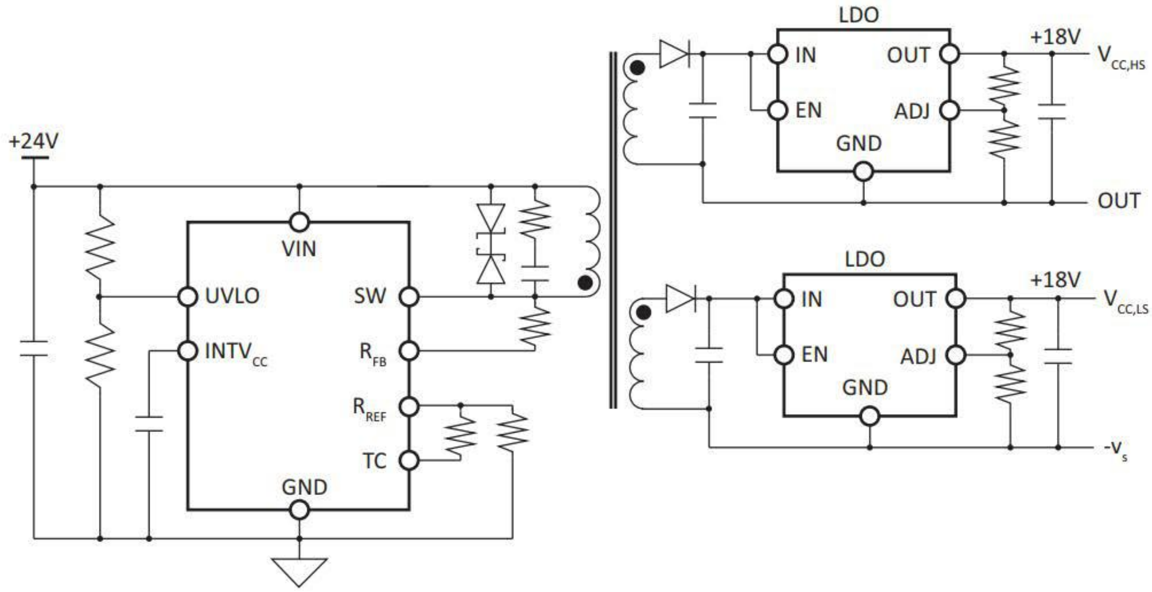
For dual-sided operation, the negative supply(-V_S) pins 40 thru 52 are now all tied to a negative voltage potential. This negative voltage potential will serve as the lowest point that the output of the half-bridge switching module will swing whereas with the single-sided output configuration this point was 0V/ground. The logic signal inputs reference has changed from ground, as it was in the single-sided output, and is now referenced to whatever the negative voltage rail is set to. This can present an issue with regards to providing a 5V logic signal to logic input pins when the negative voltage rail begins to reach large voltages. In this case it is prudent to use a signal isolation device that can provide isolated logic signals that are referenced to a larger voltage potential than ground and still appear as approximately 5V to the logic pins of the half-bridge switching module. One such device is exemplified in *Figure 4* and is also the device that is used for this application.

Figure 4: Logic Signal Isolator



The $V_{CC,LS}$ and $V_{CC,HS}$ are now independent of each other and are not tied together by a bootstrap circuit because it will no longer function to power the high side voltage correctly. This is due to the nature of the typical dual-sided output tending to switch only one side (high side or low side) during each half period of an output signal. This sort of output behavior would necessitate a more complex bootstrap network that could accommodate both positive and negative voltage swing. Instead, $V_{CC,LS}$ and $V_{CC,HS}$ will each require their own voltage that is referenced to either the negative voltage rail for $V_{CC,LS}$ or the output of the PWM amplifier for $V_{CC,HS}$. In the application, for simplicity, two dc-dc converters are used to provide the separate voltages (18V) that are required for $V_{CC,LS}$ and $V_{CC,HS}$. An alternative example of a power supply scheme that could be used to provide multiple voltages with separate references to $V_{CC,LS}$ and $V_{CC,HS}$ is pictured an *Figure 5* in the form of a fly-back converter with two windings on the secondary side of the transformer.

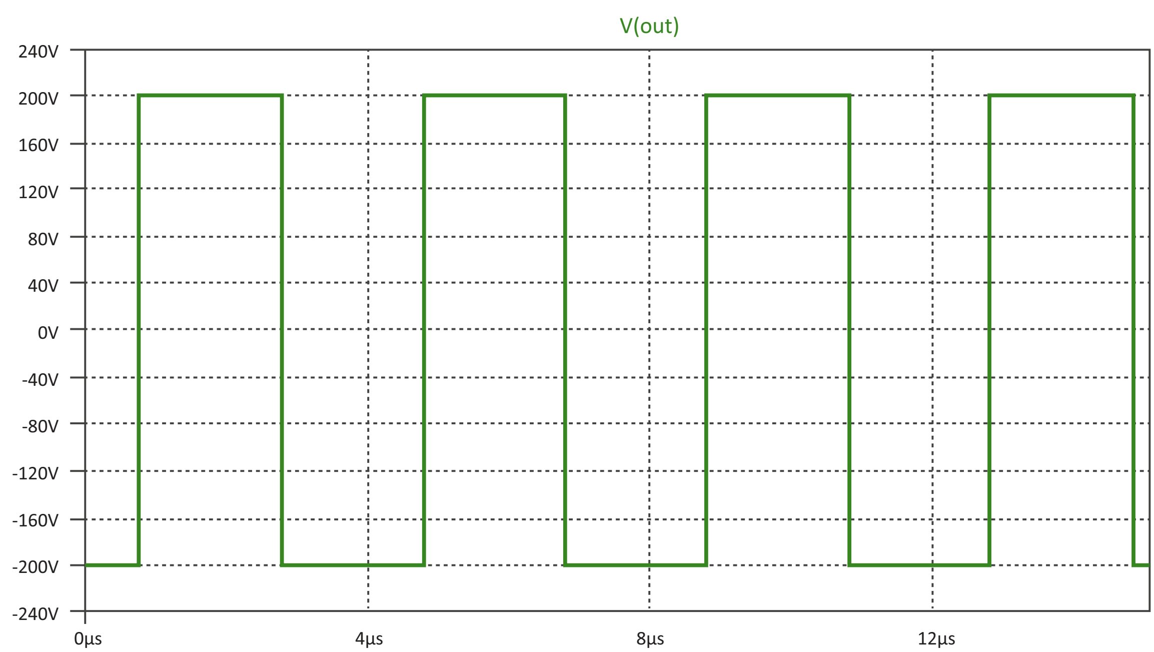
Figure 5: Fly-back Converter Example



DUAL-SIDED OUTPUT SIMULATION RESULTS

When the dual sided output bias scheme is applied to the Apex SA111, the results are as expected and illustrate what the in-lab performance should be. By applying the bias circuit elements that are mentioned in the dual-sided output configuration, the amplifier is now capable of swinging from the negative voltage rail all the way to positive voltage rail as shown in *Figure 6*.

Figure 6: Dual-sided Output Simulation Results



For the simulation to work properly for dual-sided output swing, each of the areas of attention from *Figure 3* need to be addressed. The spice simulation circuit shown in *Figure 7* is configured for single-sided output and is used as a reference for comparison to the dual-sided configuration of *Figure 8*, which reflects all the changes highlighted in *Figure 3*.

Figure 7: Single-sided Output Simulation Circuit

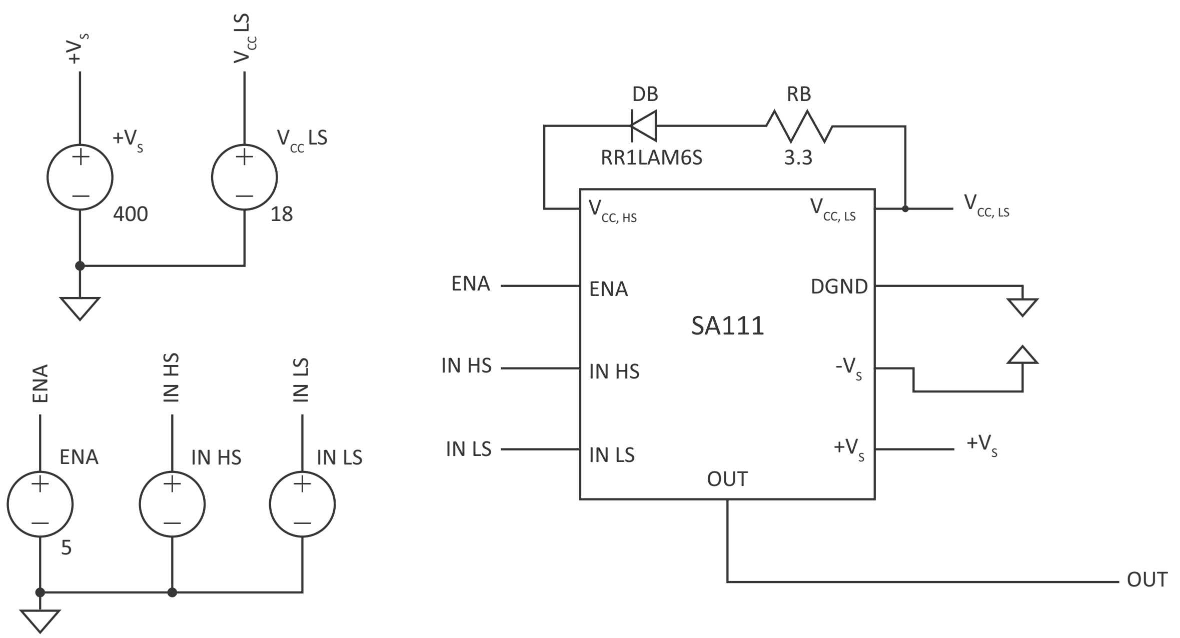


Figure 8: Dual Sided Output Simulation Circuit

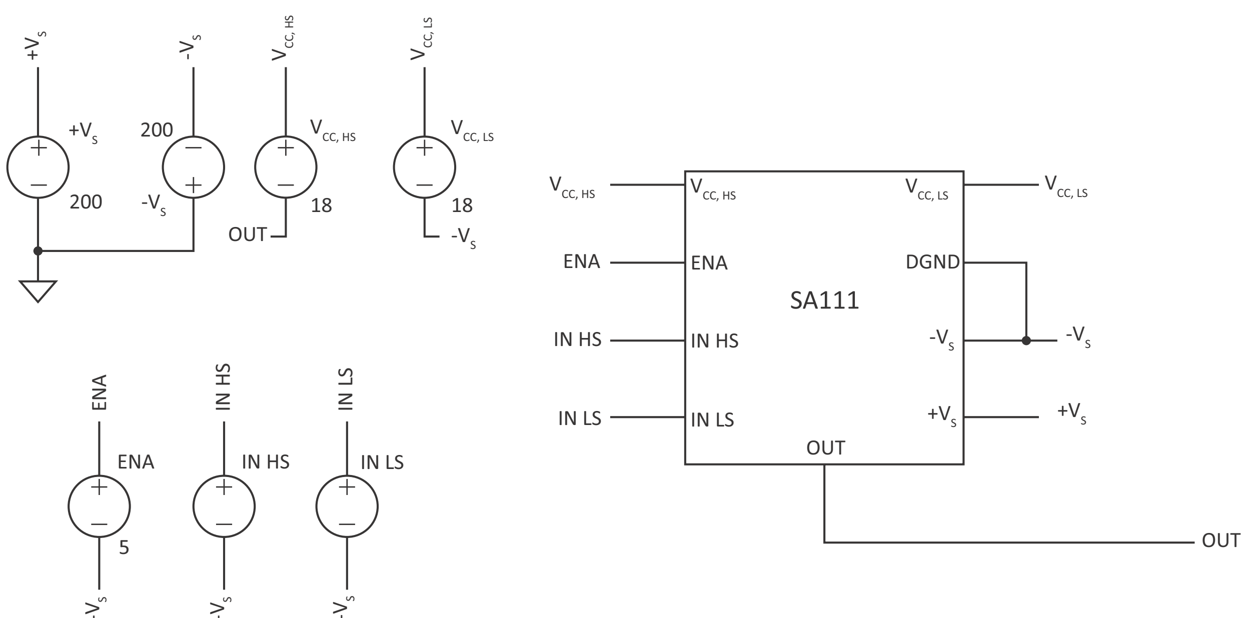


Figure 9 shows that the -V_S pin has been referenced to some negative voltage potential other than ground so that the output of the Apex SA111 can swing below the 0V line. The bootstrap network has also been removed in accordance the dual-sided output swing configuration and the $V_{CC,LS}$ and $V_{CC,HS}$ pins are now referenced to individual voltage sources.

Figure 9: Difference of Supply Reference at SA111

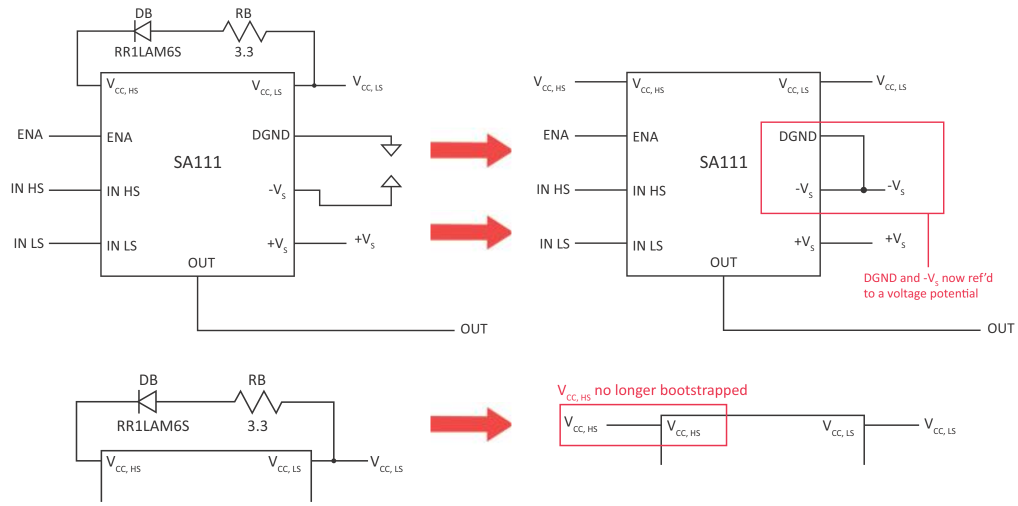
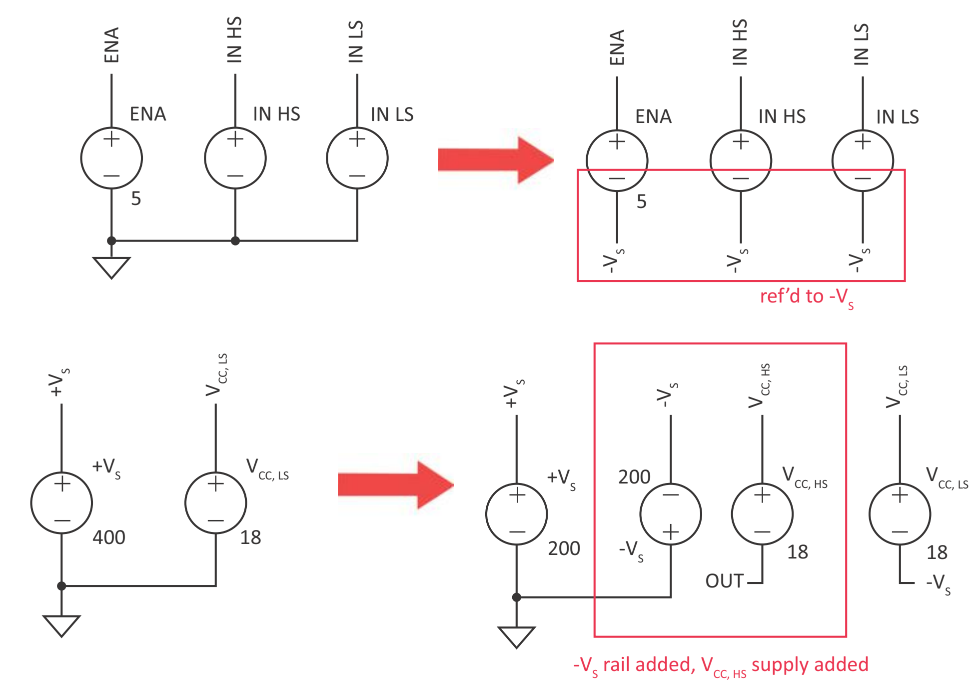


Figure 10 shows further detail as to the logic signal inputs being referenced to -V_S rather than ground. The addition of -V_S(-200V) and $V_{CC,HS}$(18V with respect to output) voltage supplies is shown as well.

Figure 10: Difference of Reference at Voltage Supplies



Logic signals as well as $V_{CC,LS}$ and $V_{CC,HS}$ can be verified in simulation in order to assure proper referencing as shown in *Figures 11 and 12*. *Figure 11* illustrates that the $V_{CC,LS}$ voltage is referenced to -Vs and is 18V more positive than -200V while $V_{CC,HS}$ is referenced to the output and is 18V more positive than what the output voltage is (200V).

Figure 11: High and Low Side V_{CC} Simulation Referenced to $-V_S$

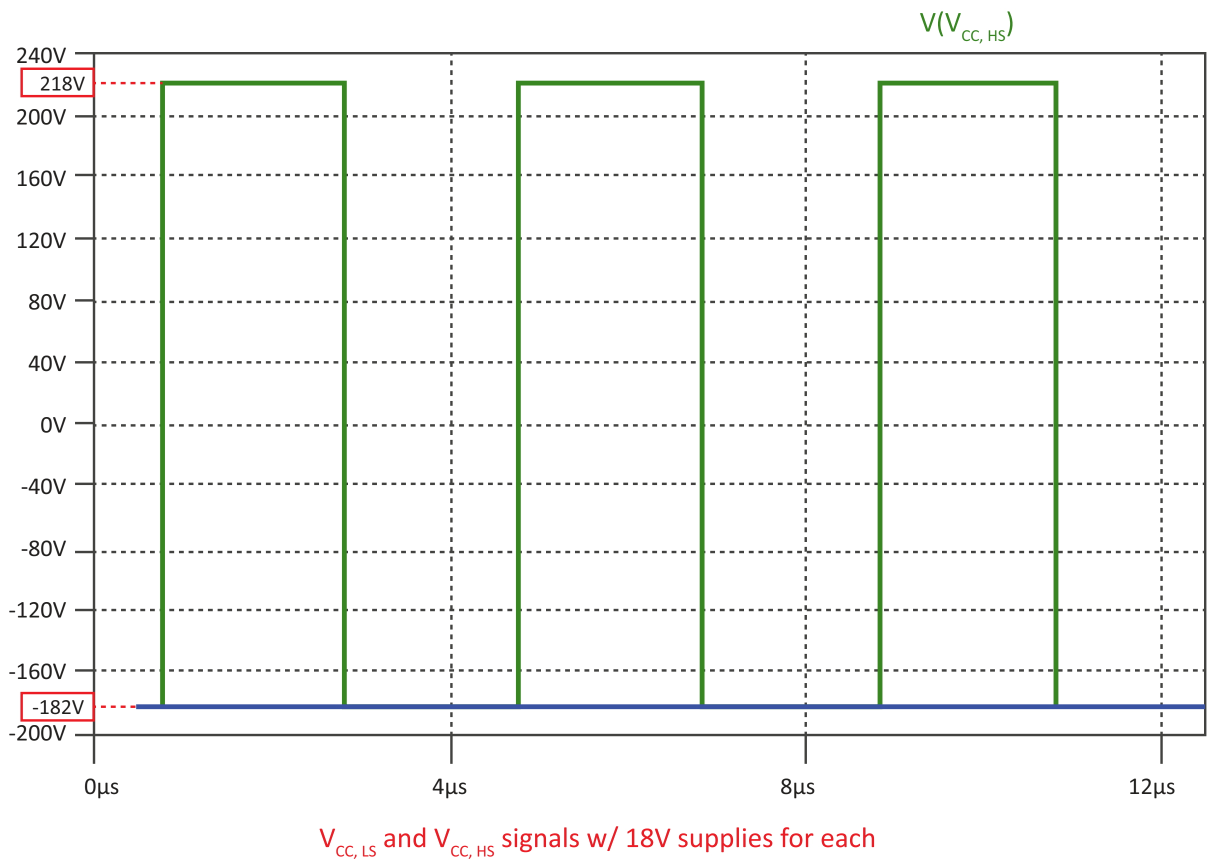
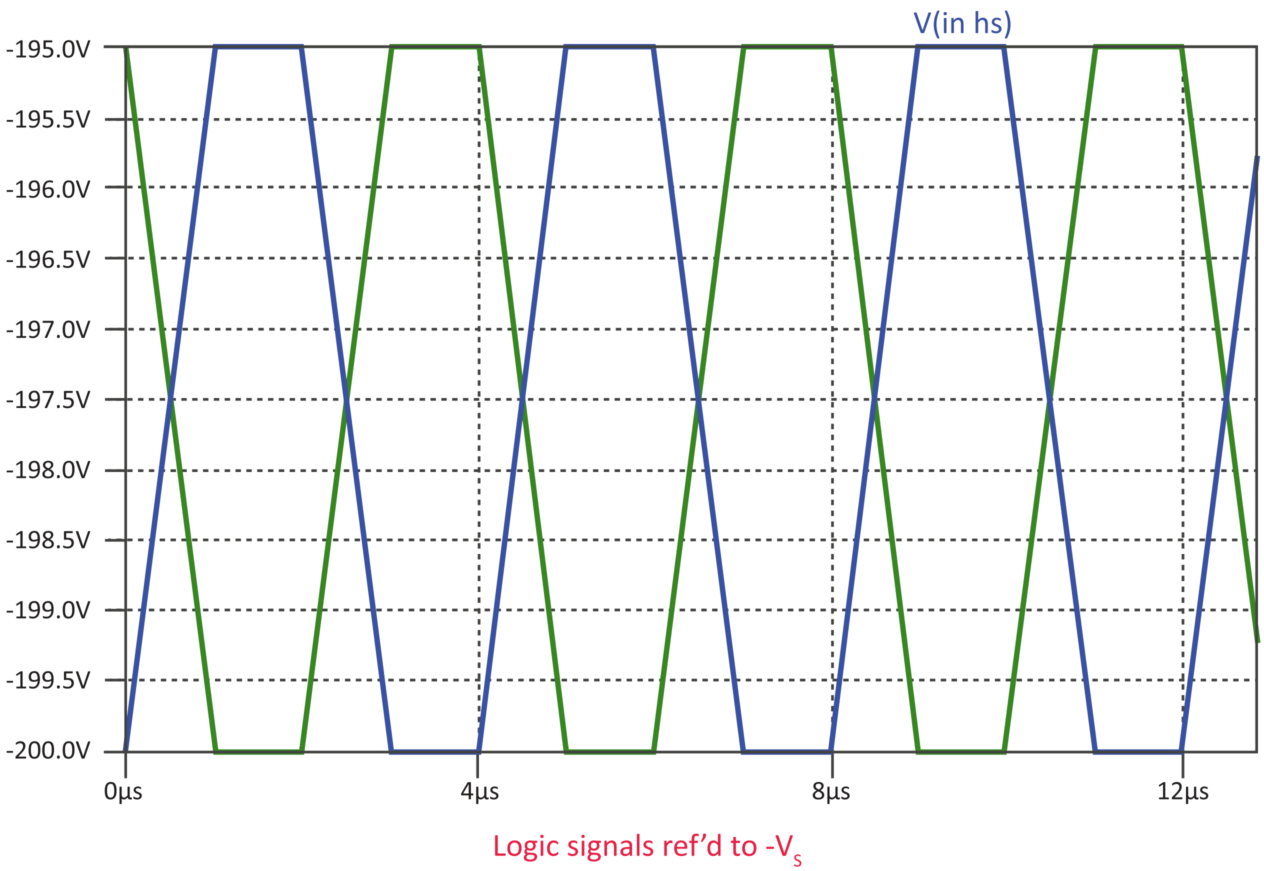


Figure 12 illustrates the logic IN_HS and IN_LS signals that are referenced to the $-V_S$ voltage rail and are approximately 5V more positive. The logic signal for ENA is not represented here because it is a DC line that would cross the plot at 5V more positive than the negative voltage rail of -200V. It is important to note that even though the magnitude of the logic signals appears to be swinging from -200V to -195V, the use of the logic signal isolation device mentioned when in-lab will allow these logic signals to appear as 5V referenced to ground for the logic signal input pins of the Apex SA111.

Figure 12: Input Logic Signals Referenced to $-V_S$

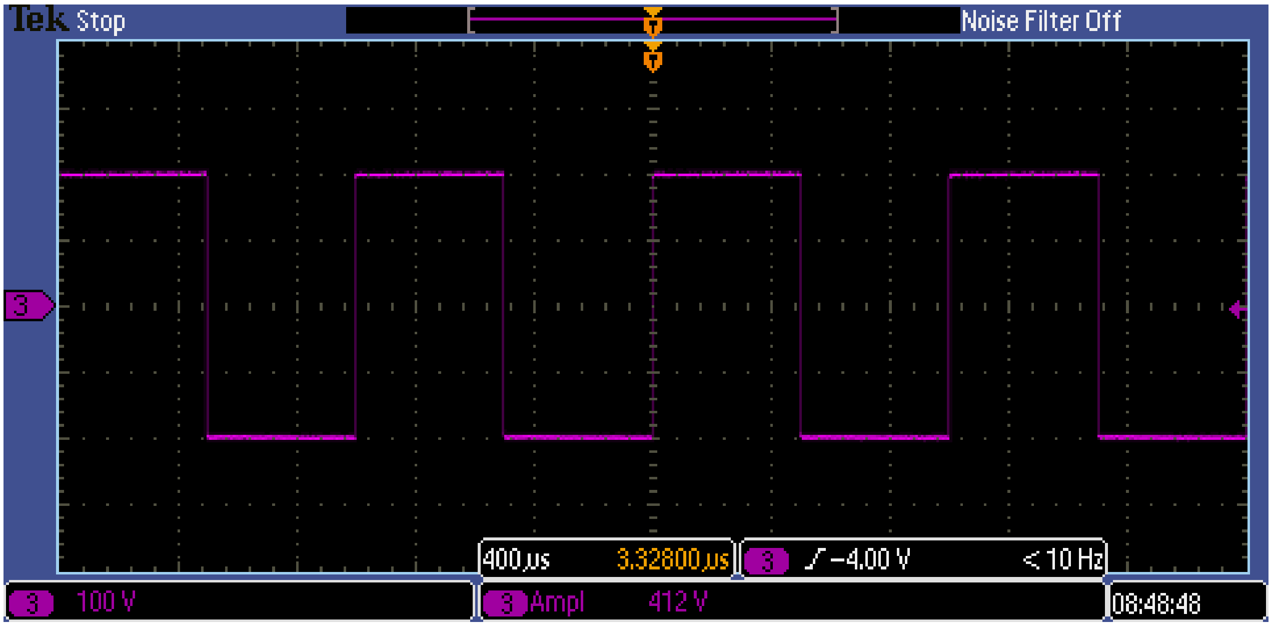


With all the bias circuit elements in place and an expected output result, this simulation work is enough evidence to test this configuration out in-lab.

COMPARISON OF REAL WORLD AND SIMULATION

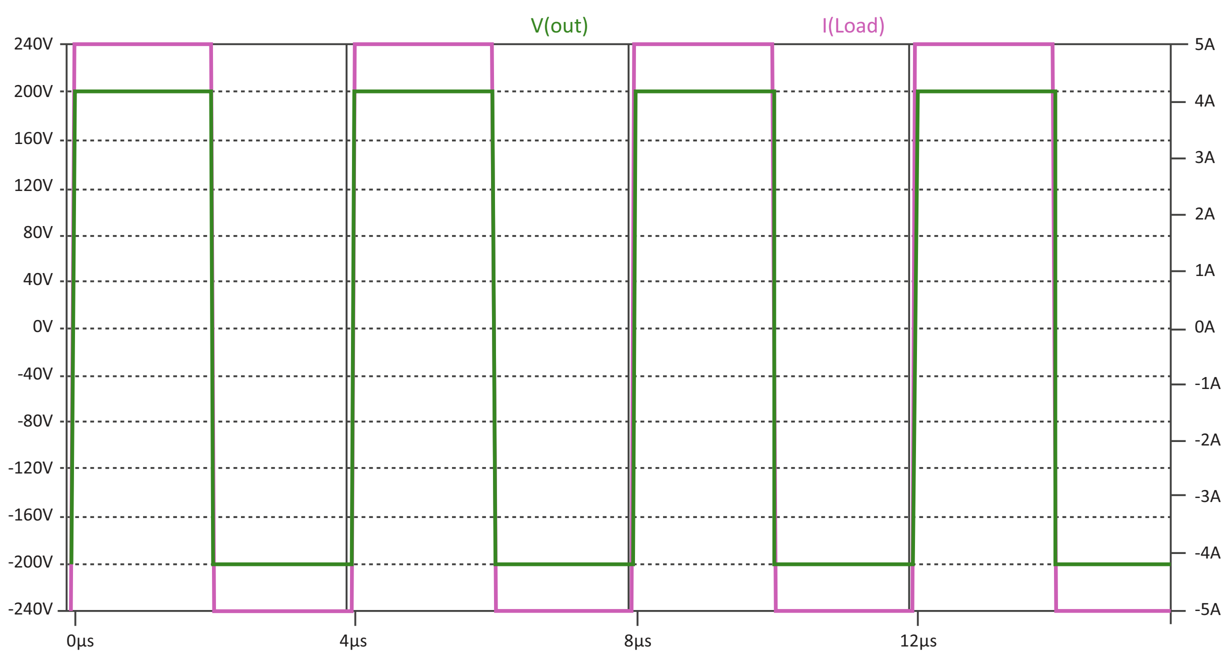
Based on simulation results, it appears that the Apex SA111 should be able to produce dual-sided output swing in-lab. When the circuit is configured and powered on, the results appear to be as expected and are exhibited in *Figure 13*.

Figure 13: Dual-sided Output Swing Bench Results



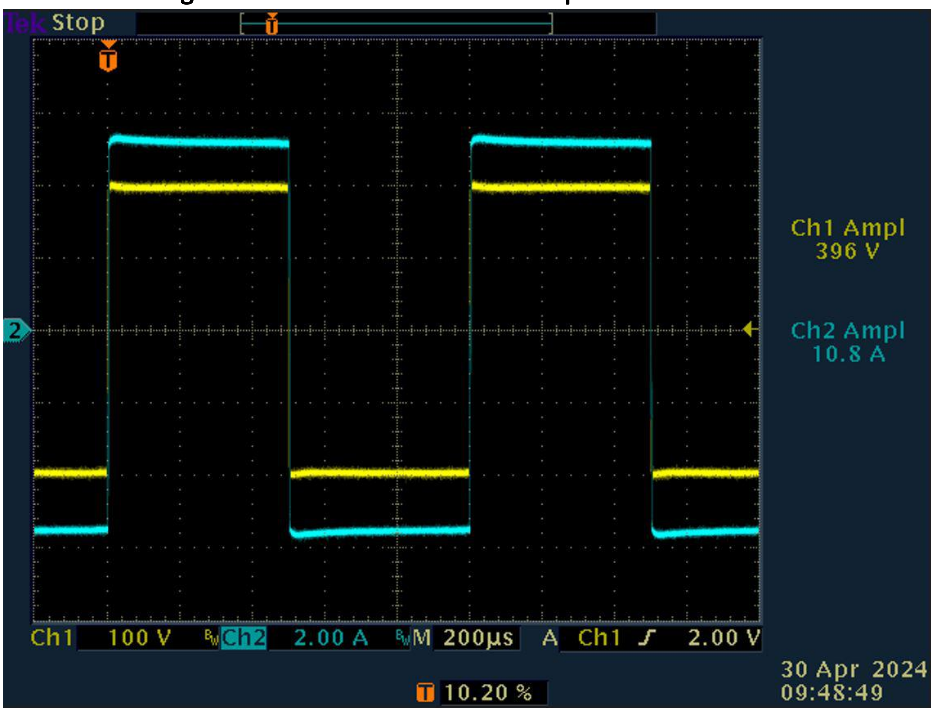
When compared to *Figure 6*, the bench results from *Figure 13* appear to confirm what was seen in the simulation. The output of the Apex SA111 can swing from -200V to 200V. Further testing of the Apex SA111 driving a current load can be seen in *Figures 14 and 15*. *Figure 14* is the result of the simulation when driving a resistive load of 40Ω to produce ±5A.

Figure 14: Loaded Dual-sided Output Simulation Results



It can be seen from the simulation scope plot that the Apex SA111 can drive current through the load resistor with positive and negative polarity. When compared to *Figure 15*, the in-lab scope plot of the same conditions, there doesn't appear to be any discernible difference in wave shape between the simulation and in-lab results. Based on the result from *Figure 15*, it appears that the Apex SA111 is also able to drive current in a dual-sided fashion that tracks the voltage at the output, again driving a ±200V voltage output across a 40Ω load resistor to generate approximately ±5A of output current.

Figure 15: Loaded Dual-sided Output Bench Results



TURNING NEGATIVE SWING TO POSITIVE OUTCOMES

When it comes to negative voltage swing from a half-bridge switching module there could be several different possibilities with respect to application uses. Traditionally, PWM motor drive is thought of as way to control and vary motor speed. With dual- sided output capability there now exists the capability to drive a motor in either direction as well as controlling speed. With regards to piezo applications, when a positive or negative pulse is applied, the polarization direction of the piezo element changes (downward for a positive pulse and upward for a negative pulse) as well as the type of actuation (compression for a positive pulse and tension for a negative pulse). This effect gives a larger range of application possibilities for piezo transducers and actuators.

PREPARATION IS KEY

The technique that has been described in this application note can be successfully applied to half-bridge switching modules within the Apex PWM portfolio and should also find success with alternative SiC half-bridge switching modules that have a similar configurable bias scheme. The most important thing to remember when implementing a bias scheme like what is required for dual-sided output is to be very methodical and assure that all supply voltages and logic signals are correct before proceeding with device power on. Ensuring that attention is paid to the little details will result in successful experimentation.

APPENDIX FOR FIGURE COMPARISON

SINGLE-SIDED OUTPUT COMPARISON

Figure 16: Single-sided Output Simulation Results

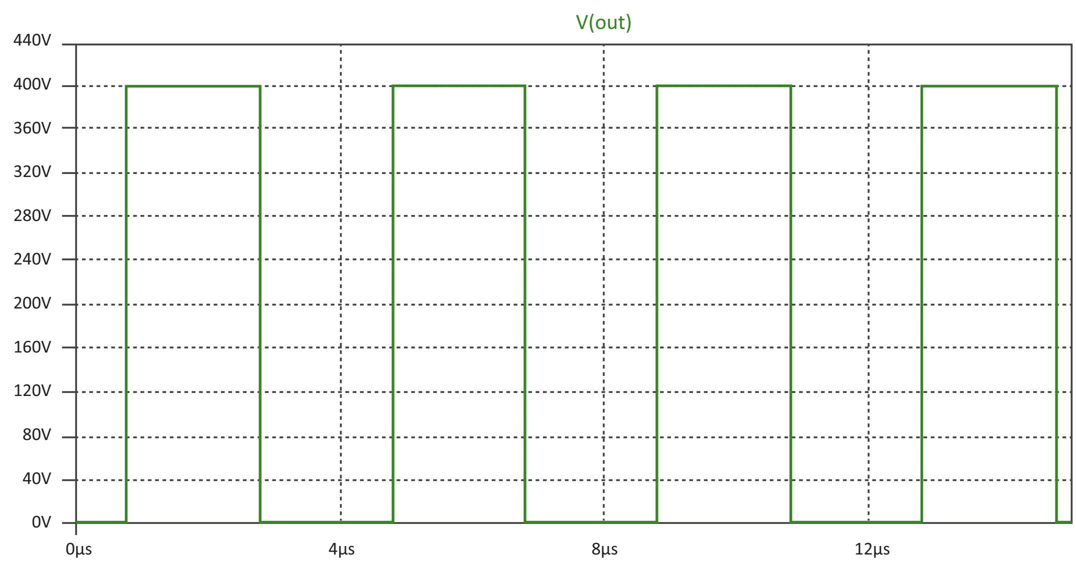
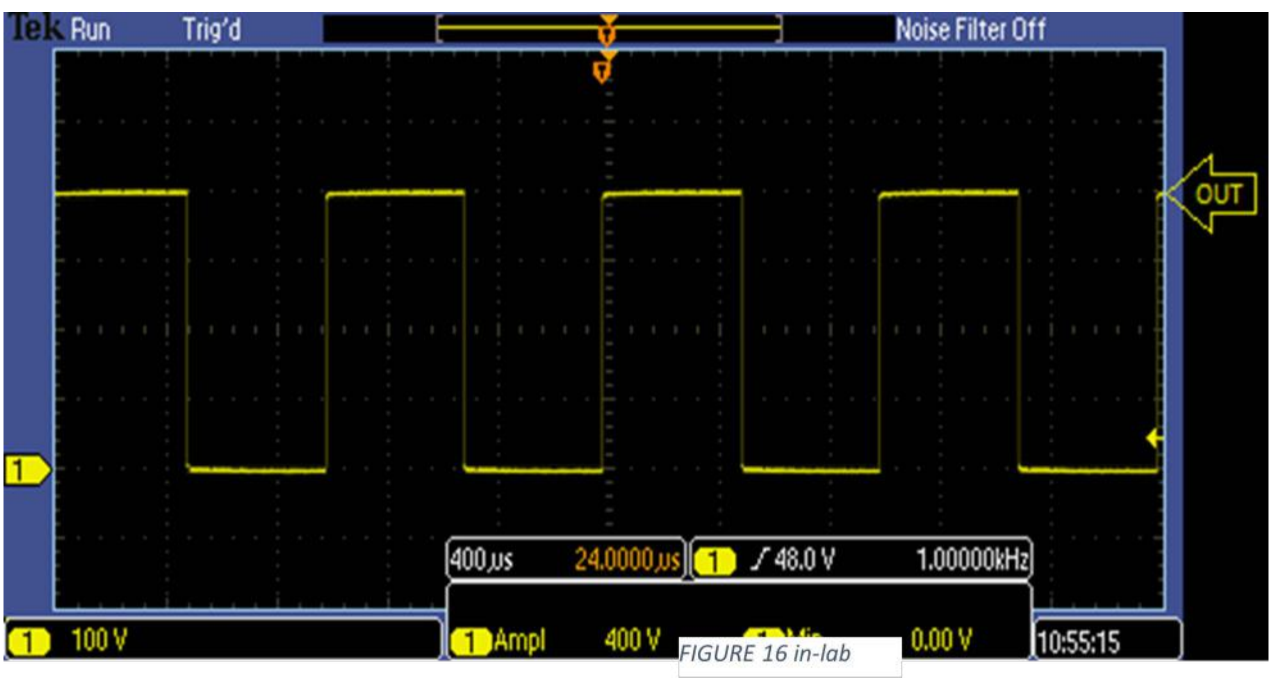


Figure 17: Single-sided Output Bench Results



CIRCUIT DIAGRAM COMPARISON

Figure 18: Single-sided Circuit Diagram

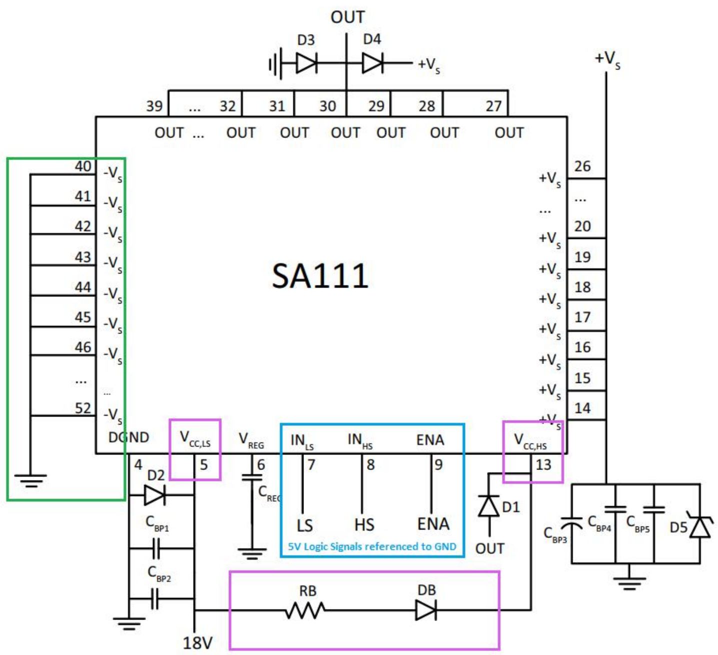
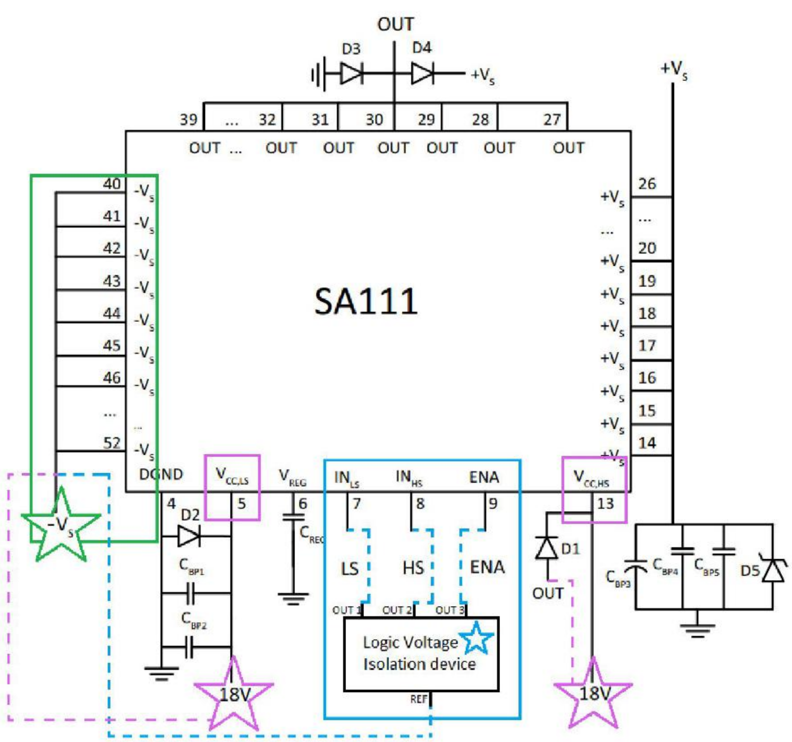


Figure 19: Dual-sided Circuit Diagram



COMPARISON (UNLOADED)

Figure 20: Dual-sided Output Simulation Results

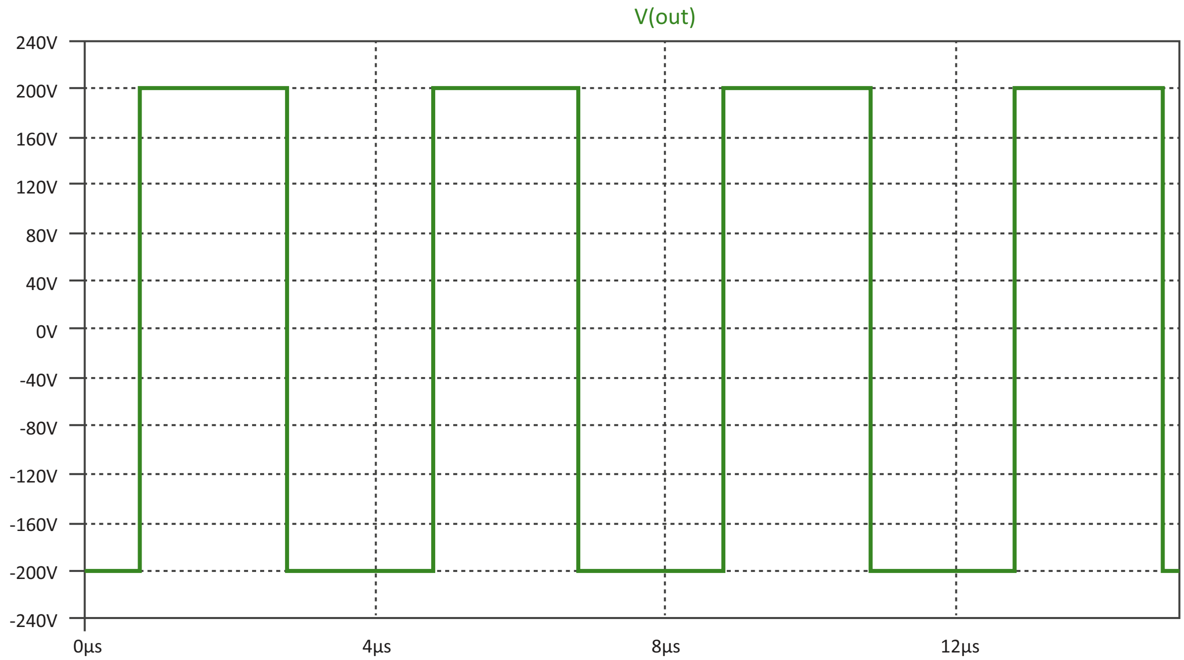
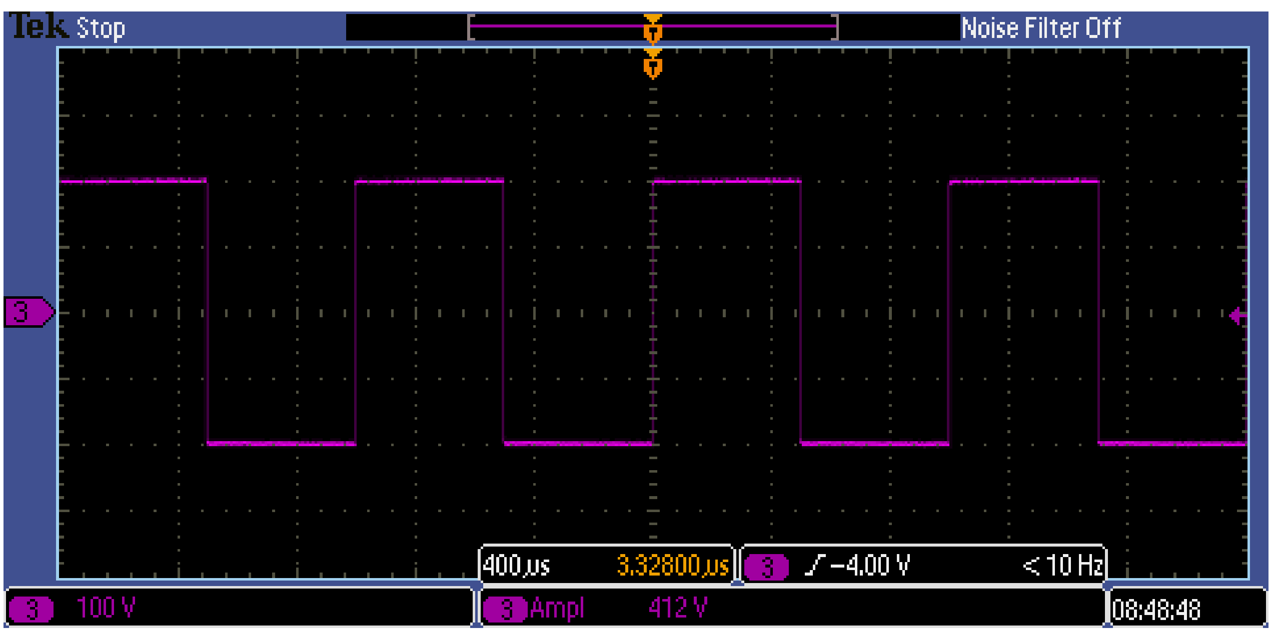


Figure 21: Dual-sided Output Bench Results



DUAL-SIDED OUTPUT COMPARISON (LOADED)

Figure 22: Loaded Dual-sided Output Simulation Results

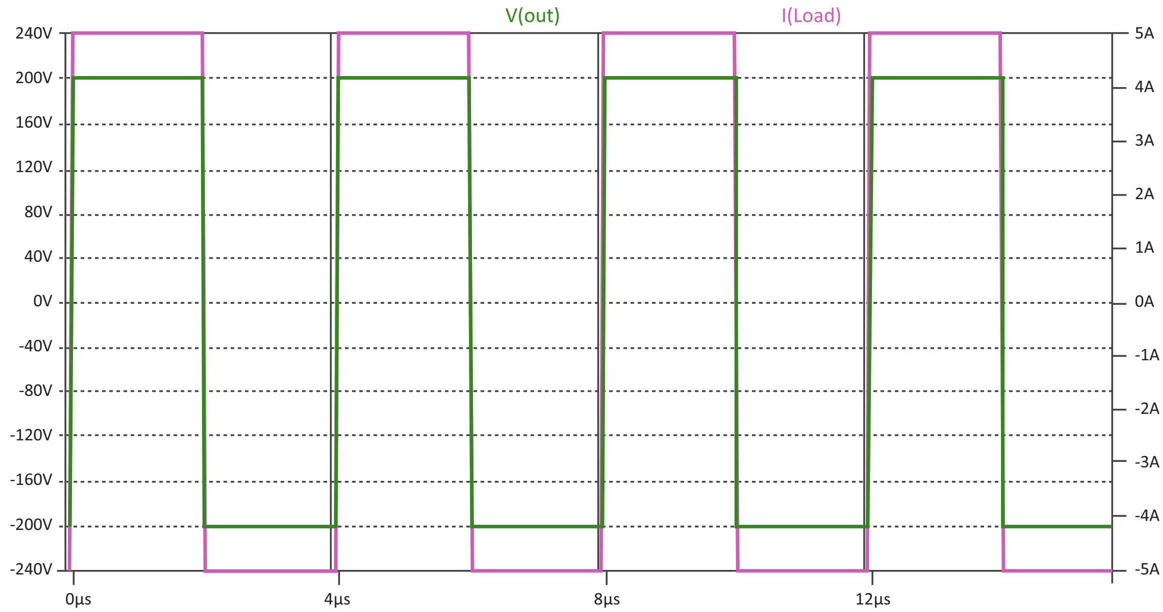
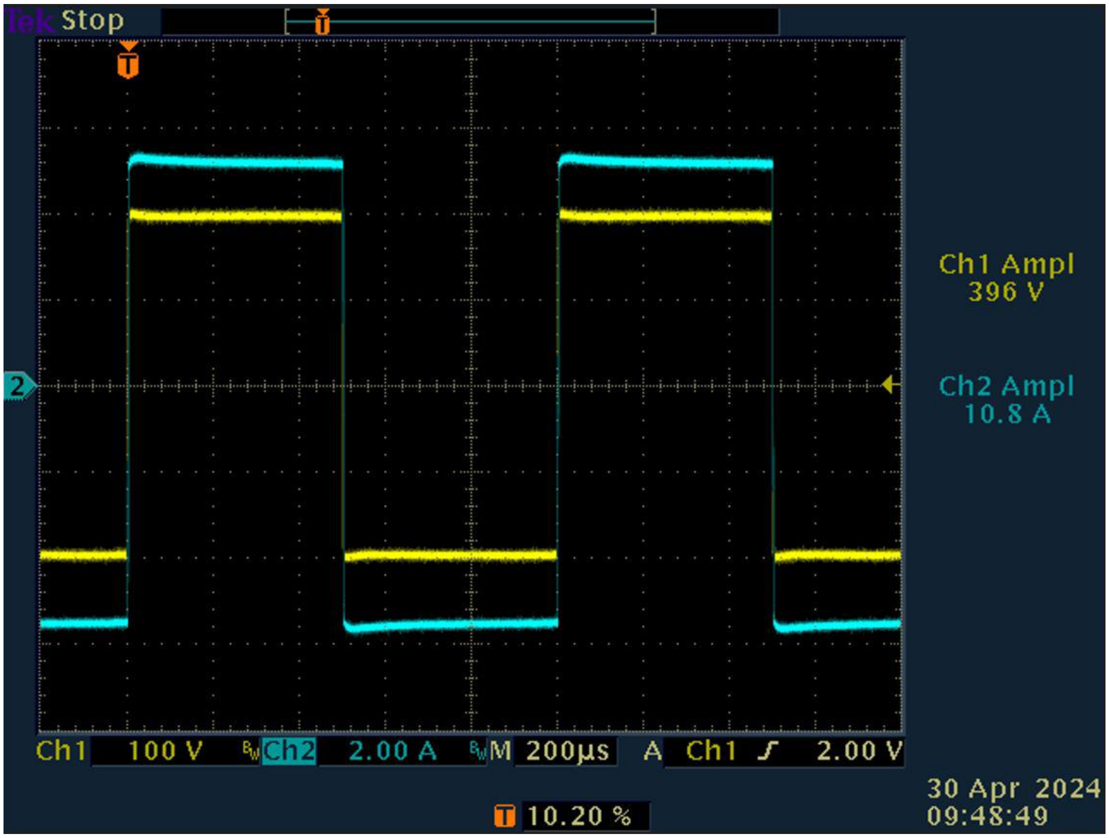


Figure 23: Loaded Dual-sided Output Bench Results



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