Application Report
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# Battery Voltage Tracking Limiter and Brown-Out Protection

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**ABSTRACT**

Audio amplifiers such as TAS2562, TAS2563, TAS2764, TAS2770, and others are often used in battery powered applications such as Bluetooth speakers, cell phones, PCs, and other handheld electronics may demand more power than can be normally provided by the battery at the end of a typical charge cycle. Battery voltage (VBAT) tracking and brown out protection features are available to help prolong usable battery life and prevent the audio power demands from causing the entire system to shutdown prematurely.

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## Trademarks

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## 1 Introduction

In battery powered audio applications the user may experience a change in audible performance as the device begins to deplete battery charge. When the battery voltage (VBAT) begins to droop, the supply headroom required to prevent audio clipping will be reduced. This may result in distortion of the output audio if severe enough. Additionally, as the battery voltage continues to decrease, the ability to supply current tends to diminish. If an audio amplifier continues to drive significant current into the speaker it can cause the system battery voltage to dip below normal system operating levels which will result with the system shutting down or possibly causing electrical damage to other devices sharing the same supply. This type of event is commonly known as Brown Out.

As a solution to this problem, many Texas Instruments audio amplifiers include programmable VBAT tracking limiter and brown-out protection functions that help the designer to vary peak power consumption over the life of the battery, protect the system from brown out events, and extend usable battery life.

## 2 Benefits

The voltage limiter and brown out protection features provide control which may improve the end user experience. Benefits from using these features include:

- Helps prevent system wide supply collapse at the end of battery charge cycle
- Allows system to shut down in controlled manner
- Helps prevent output from clipping as operating headroom is reduced
- Provides control of maximum output power for all battery levels
- Helps extend battery life
- The audio amplifier automatically adjusts itself requiring no software to adjust audio content to achieve desired performance

## 3 Brown Out Protection and Limiter Design

The VBAT tracking limiter will monitor the output voltage using an integrated Successive Approximation Register (SAR) converter while the outputs are active. The SAR is continuously sampling the VBAT voltage and feeding the result back to the Brown Out Protection and Limiter block. When the Brown Out Protection / Limiter detects that VBAT has gone below threshold it will update automatically and reduce the digital gain on the front end of the signal path as necessary to match the configuration programmed by the user.

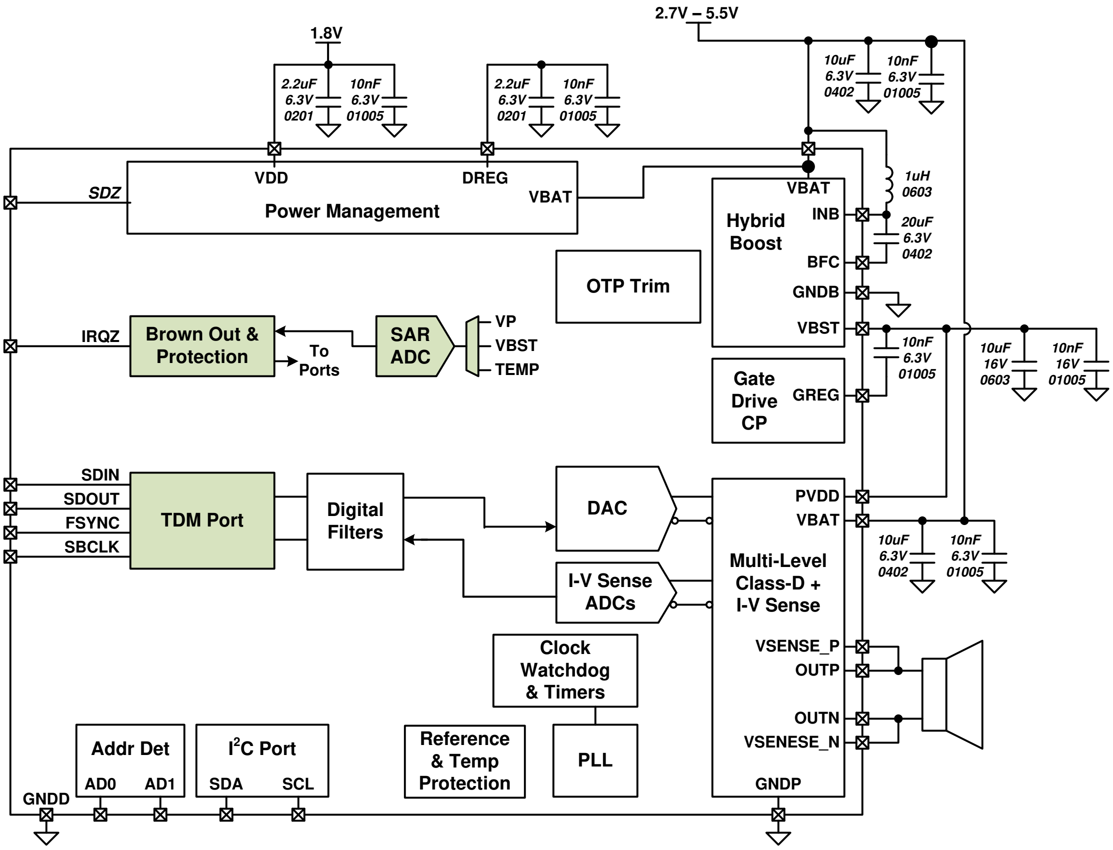



**Figure 1. TAS2562 Block Diagram**

## 4 VBAT tracking limiter

The battery tracking voltage limiter can be customized to the end application power specifications. The limiter may also be configured to reduce gain gradually to avoid impacting the listening experience. Once VBAT recovers, the gain will be slowly restored to the programmed operating condition.

The advantage of this solution is that it dynamically configures the Automatic Gain Control (AGC) to help extend battery life, improve the end listening experience for the user, and does not require additional adjustments to the audio stream provided to by the host.

An example of the battery tracking limiter actively adjusting gain can be seen in the scope capture in Figure 2. In this example the battery voltage is provided by a bench top supply and is ramped down over time causing the limiter to engage.

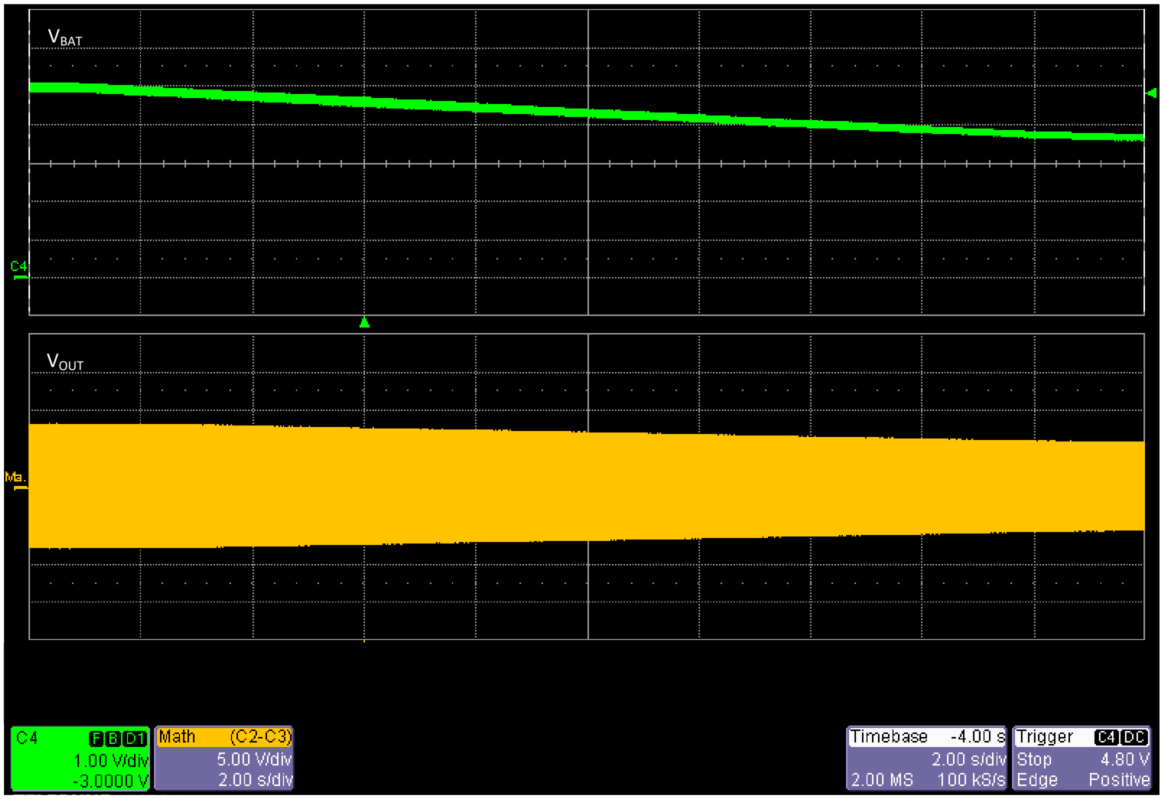



**Figure 2. Limiter Attack Response**

Figure 2 shows that over a 20 second period that the amplitude is slowly reducing in response to the downward ramp of the VBAT supply voltage. Normally in a real scenario the battery voltage would decay much more slowly than what is demonstrated here. The attenuation settings may be set to produce a smaller overall shift in signal amplitude as well. Figure 2 was produced using the profile shown in Figure 3.

The voltage tracking limiter has several key parameters which control the behavior of the device as battery conditions change.

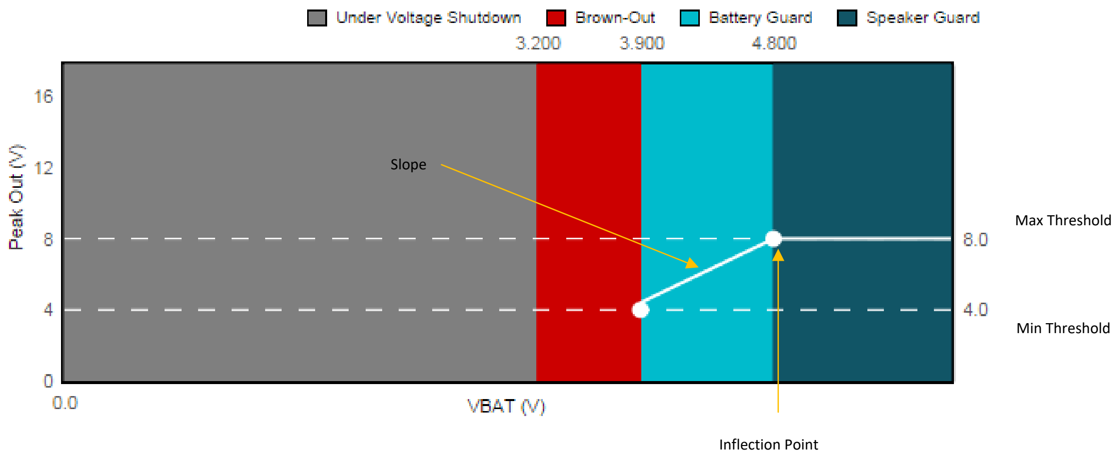



**Figure 3. Battery Tracking Limiter Profile**

### 4.1 Threshold

The threshold has two settings which must be configured. The maximum threshold will determine the maximum voltage which the Class-D will output for all battery voltages. The minimum threshold will set the lowest voltage which the AGC will limit. In operation, this dictates the gain range which the AGC will utilize.

### 4.2 Inflection Point and Slope

The inflection point sets the VBAT voltage where the AGC will begin to reduce gain below the maximum threshold. As VBAT continues to decay below this point, the AGC will track the slope setting until the minimum threshold is achieved. When the slope setting is increased the amplifier will reach the minimum threshold at higher battery voltages.

### 4.3 Attack

The AGC will adjust the gain gradually based on user settings when it is necessary to limit the maximum output voltage. The speed of this attack can be set through the step size and attack rate. The step size may vary from a minimum step of 0.25 dB to a maximum step of 2.5 dB.

The attack rate determines how quickly these steps occur. Attack rate ranges 1 sample per step all the way to 128 samples per step. The samples are a function of the frame clock frequency. Fewer samples per step will result in a faster overall attack.

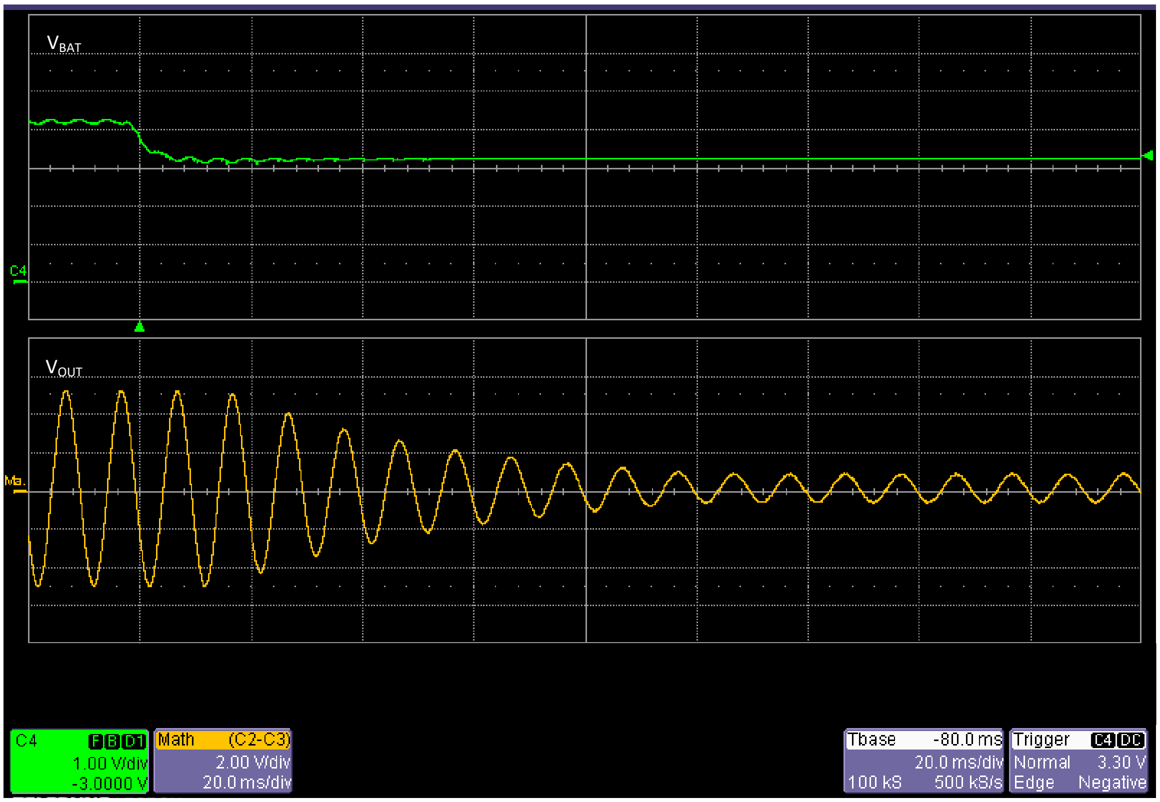



**Figure 4. Minimum Attack Rate**

The attack example in Figure 4 is set to 128 samples per step, 0.5 dB per step, and 16.5 dB maximum attenuation. However, the signal is already somewhat attenuated by the limiter. In effect the amplifier only needs to attenuate an additional 13.5 dB. With a sample rate of 48 kHz the attack lasts over a total of 72 ms.

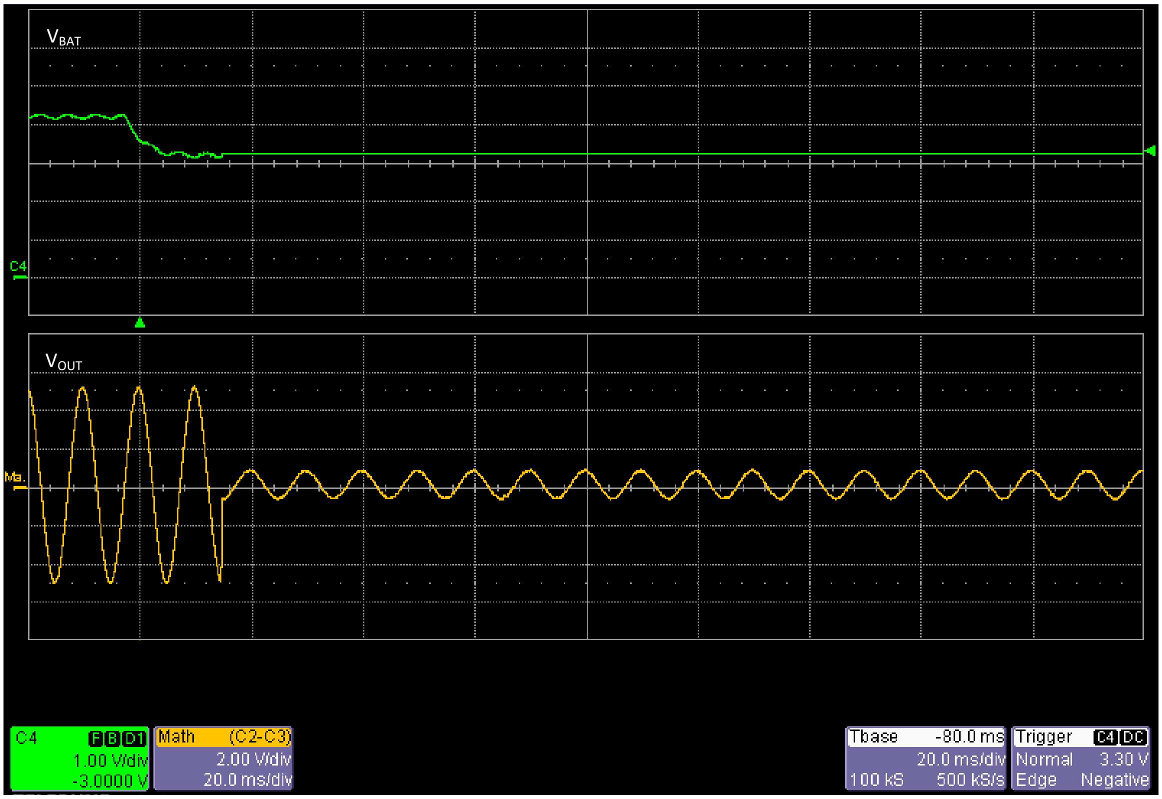



**Figure 5. Maximum Attack Rate**

The Figure 5 uses 1 sample per step, 2 dB per step, and a total of 13.5 dB maximum attenuation. With a sample rate of 48 kHz the attack takes only 140 us.

### 4.4 Hold Time

Once the limiter has finished the attack, it is possible that the battery voltage may recover. At this point the limiter will attempt to restore the gain to its previous setting. It must first satisfy the hold time. This can help prevent the limiter from entering a perpetual attack/release cycle which could be observed by the end user. An example of this behavior is shown in Section 5.

### 4.5 Release

The release settings are also configurable similar to the attack settings. There is a separate release step control with the same range as the attack. Release rate typically varies from 10 samples per step to 1280 samples per step and step size varies from 0.25 dB to 2 dB. This can allow a full release from maximum attenuation to last anywhere from 1.7 ms to 1.76 seconds.

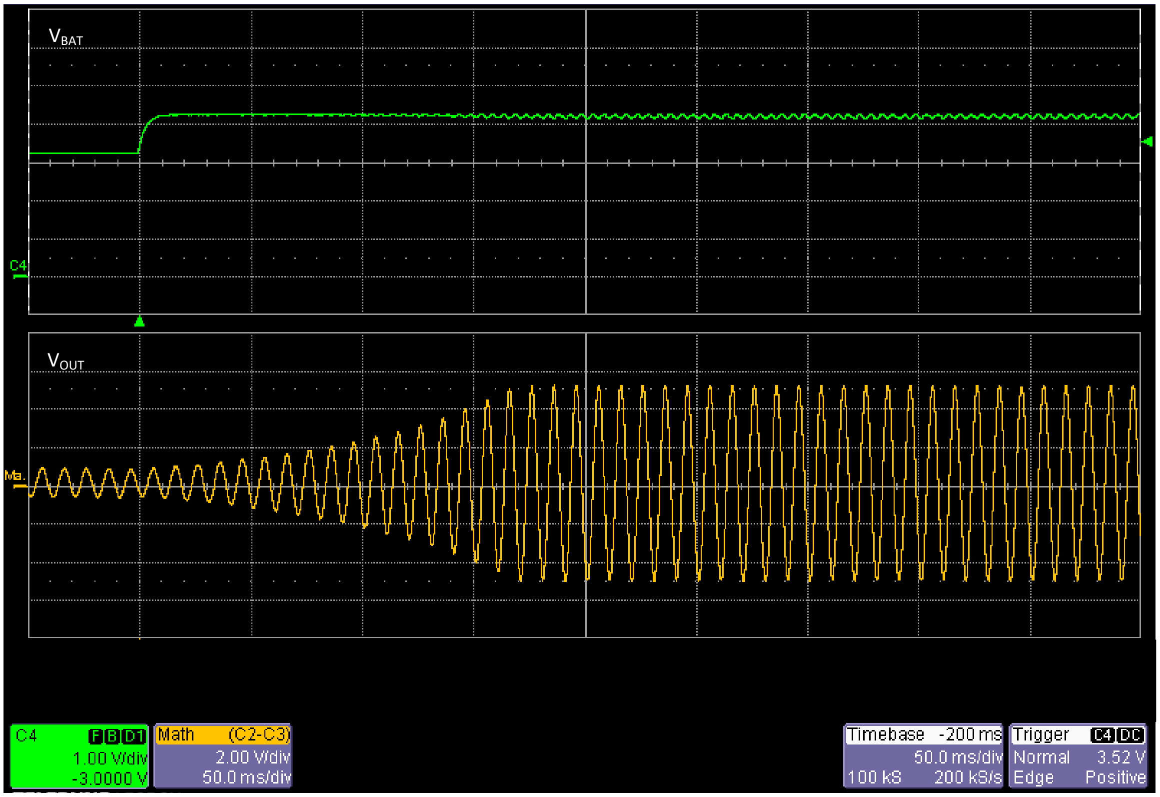



**Figure 6. Release Profile**

In Figure 6, we release 13.5 dB with the rate set to 160 samples per step and a step size of 0.25 dB. The result is a gradual release over 180 ms.

## 5 Brown Out Protection (BOP)

The BOP feature also utilizes internal VBAT tracking. When BOP is triggered, it can respond in one of two ways. Either it will shut-down the audio amplifier and put it in a low power state, or it will attack to a maximum gain attenuation setting. The benefit of this function is to prevent system level collapse that would impact resources outside of the audio amplifier. It allows the system time to respond to the low voltage condition and properly shutdown.

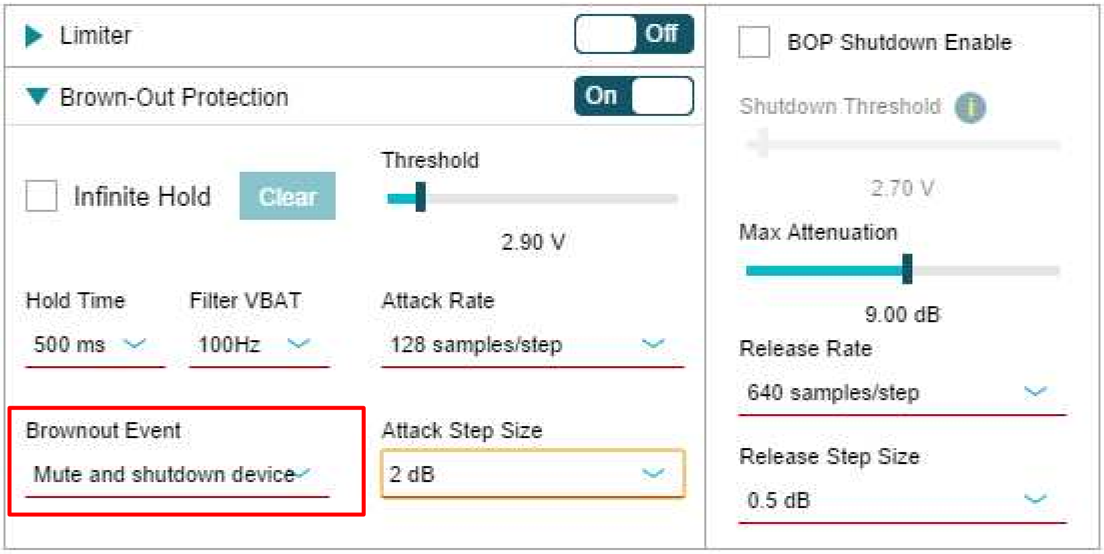



**Figure 7. BOP Profile Settings**

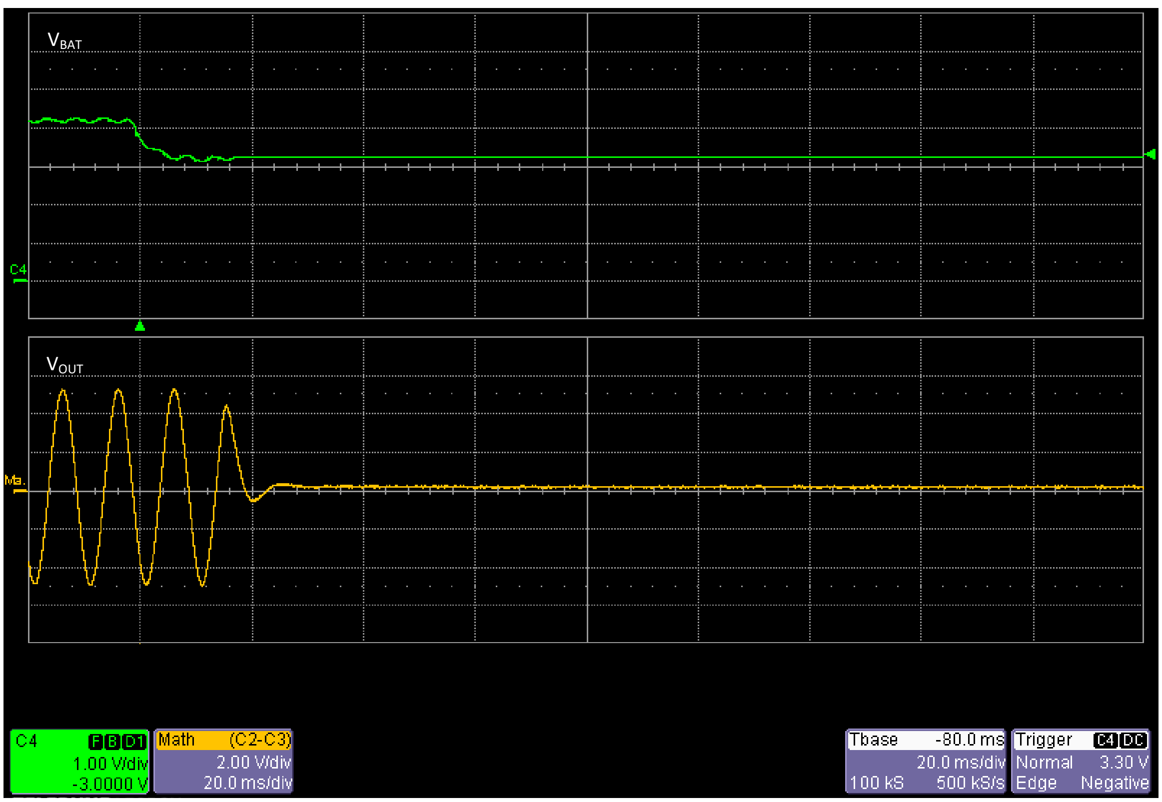


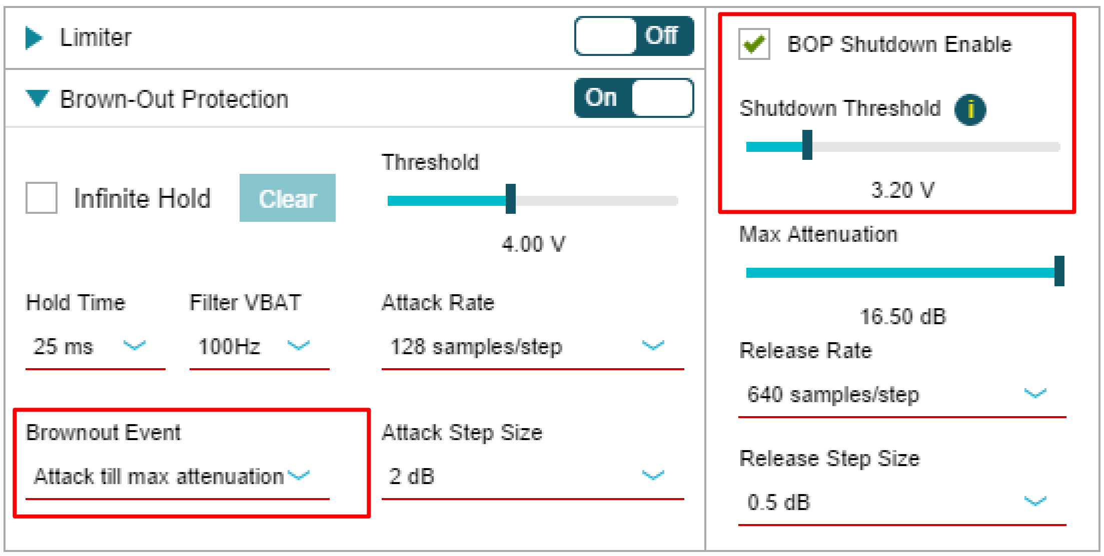

**Figure 8. BOP Mute and Shut Down**

Brown out protection may be set for infinite hold. When this is selected the brown out event will not reset until the device transitions through either mute or shutdown.

With infinite hold disabled, BOP operates much like the voltage limiter. It has independent attack settings from the limiter, but will share the release settings.

A separate Max Attenuation control is also available. This setting differs from the minimum voltage threshold which governs the limiter response. Max Attenuation sets an absolute limit for attenuation regardless of the limiter profile. It is typically should be set at or lower than the minimum voltage threshold for the AGC and is used primarily with the brown out protection feature. When attacking to max attenuation, the brown out protection will automatically step all the way to this attenuation level and override the limiter controls. When infinite hold is disabled, attack and release behavior for this state are similar to that of the AGC. However, if the AGC limiter is enabled, the device will restore the outputs to the match the state of the limiter profile and battery voltage conditions. This allows the system to keep audio active at a minimum level until the battery is recharged or the system is shut down appropriately. Attacking to max attenuation during brown out protection may be useful in applications where audio feedback to the user is needed at all times the device is powered on.

TAS2562 and TAS2563 also include a feature that allows for a staged BOP attack. When set to attack to maximum attenuation, a second BOP may be set which will trigger BOP shutdown. This provides a more sophisticated approach when operating near system brown out levels.



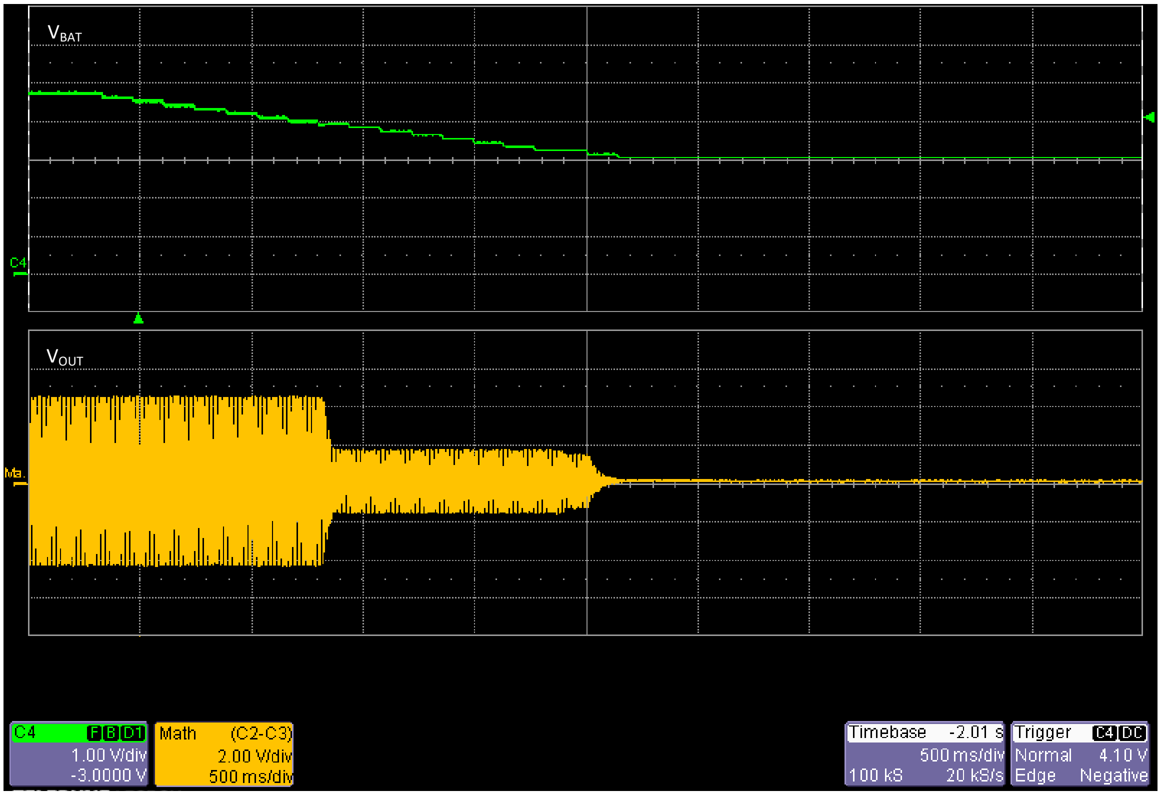



**Figure 9. Two Stage BOP Response**

Notice here at 4 V on VBAT that the BOP feature attacks to the maximum attenuation, but as VBAT continues to drop it stays steady up until crossing the 3.2 V threshold. At this time it initiates a full mute and shutdown sequence and puts the device in software shutdown to preserve the system for as long as possible.

## 6 System Testing

To demonstrate the complete response of the limiter and BOP when in use together the following setup was used.

- VBAT = 5 V - 3.5 V
- Vth MAX = 8 V
- Vth MIN = 4 V
- Inflection point = 4.8 V
- Slope = 4 V/V
- Max Attenuation = -16.5 dB
- BOP threshold = 3.6 V

The supply voltage was ramped up and down repeatedly to produce the following output response.

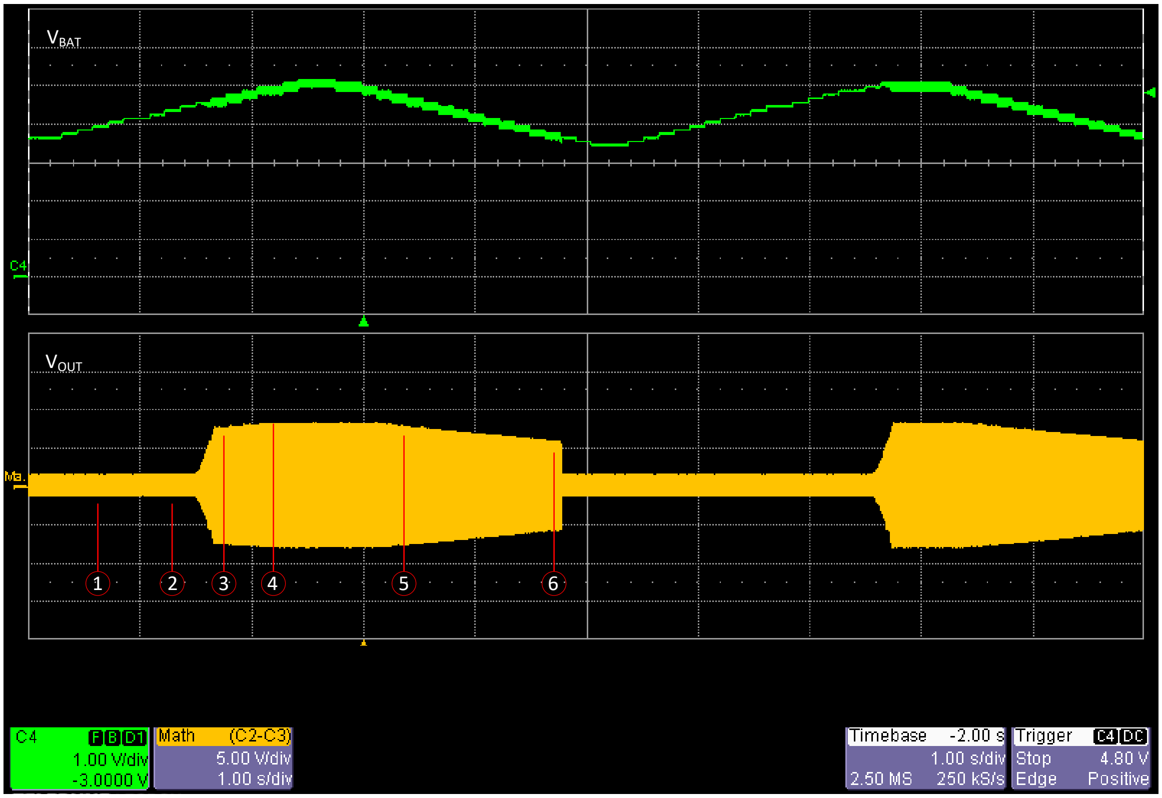



**Figure 10. Supply Ramp Test**

Various operation stages can be observed

## 6.1 BOP (1)

Here the device is set to attack to maximum attenuation instead of shutting down. With BOP max attenuation set to the highest level we see a significant drop in total output power. This could be adjusted to suit the end application in order to make the impact to the listening experience less dramatic.

## 6.2 BOP Release (2)

Once the supply voltage has reached a high enough level, the device releases the BOP. However, in this scenario the supply voltage was not fully restored yet. Instead the AGC takes control before the maximum output voltage is achieved.

## 6.3 Limiter Release (3)

Until VBAT is restored above the inflection point setting, the limiter continues to track the supply and release as appropriate.

## 6.4 Maximum Output (4)

This represents the normal use case for the amplifier with a fully charged battery. Here we are able to achieve our maximum output voltage as set by the upper threshold.

## 6.5 Limiter Attack (5)

Once the supply voltage has again dropped below the inflection point, we see the limiter tracking engage and gradually adjust the gain. This continues until the BOP threshold is reached

### 6.6 BOP Attack (6)

Once the BOP threshold is satisfied, the BOP attack takes over and immediately attacks to the maximum attenuation.

## 7 Design Consideration

If the attack and release settings are set too aggressively for either the AGC or BOP, it is possible for a pumping behavior to be observed as shown in the figure below. In this example the BOP attack rate is very abrupt and the attenuation is set to the maximum. The VBAT supply was set with the output voltage just above the BOP threshold voltage and then the compliance current was decreased until the resulting ripple would trigger BOP. As a result we can observe a very dramatic drop in output voltage when the limiter attacks. Once the attack happens, VBAT recovers just enough allow the amplifier to release. This produces a repetitive attack and release cycle which produces an undesirable pumping behavior.

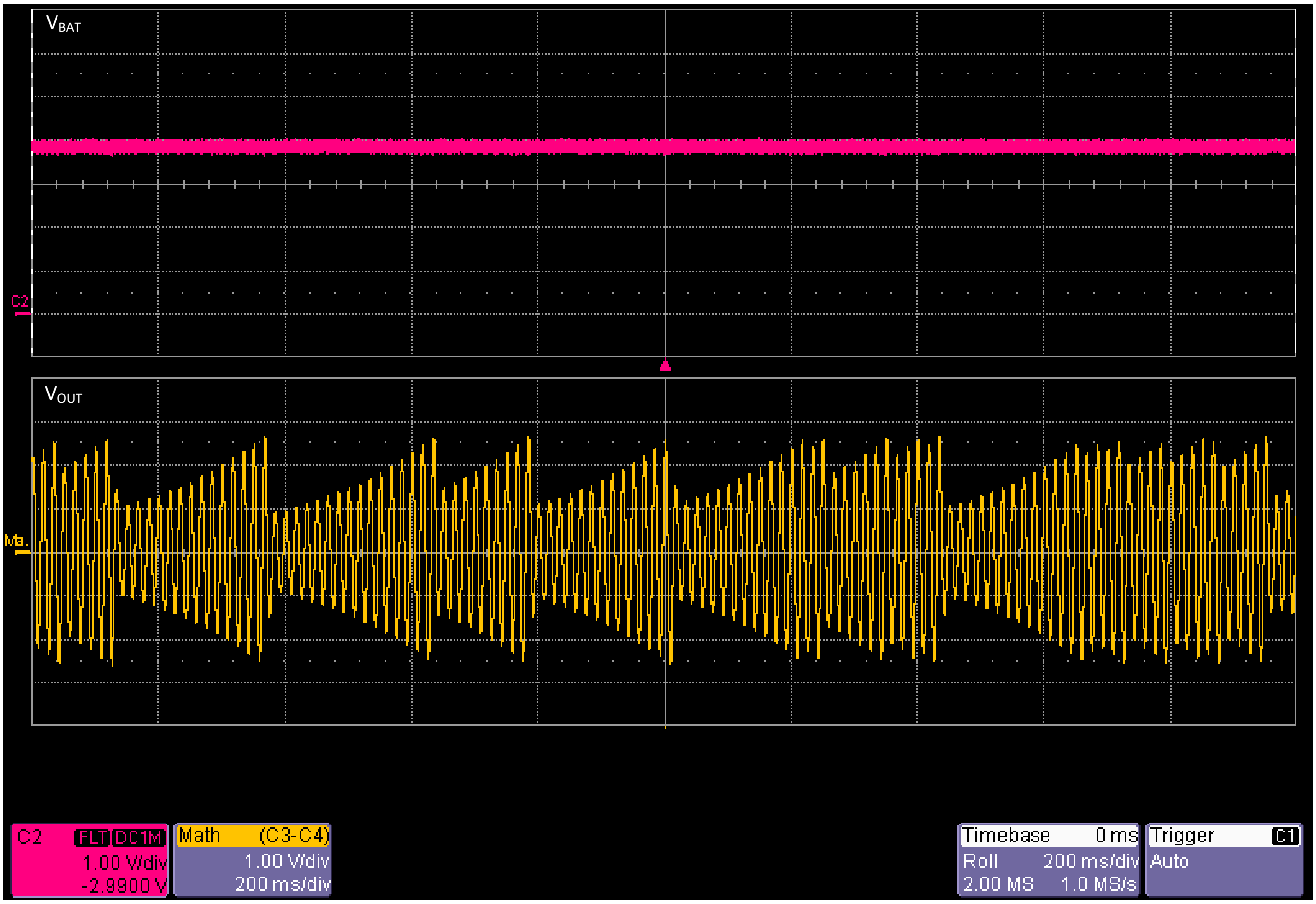



**Figure 11. Limiter Pumping Behavior**

If the settings force the attack and release to occur quickly enough, then it may produce audible artifacts. Notice the BOP settings in Figure 12 that were used to create the pumping behavior. Here the release is relatively slow, but attack is set to the maximum rate. Also, the attenuation is set to the maximum and VBAT filtering is not used.

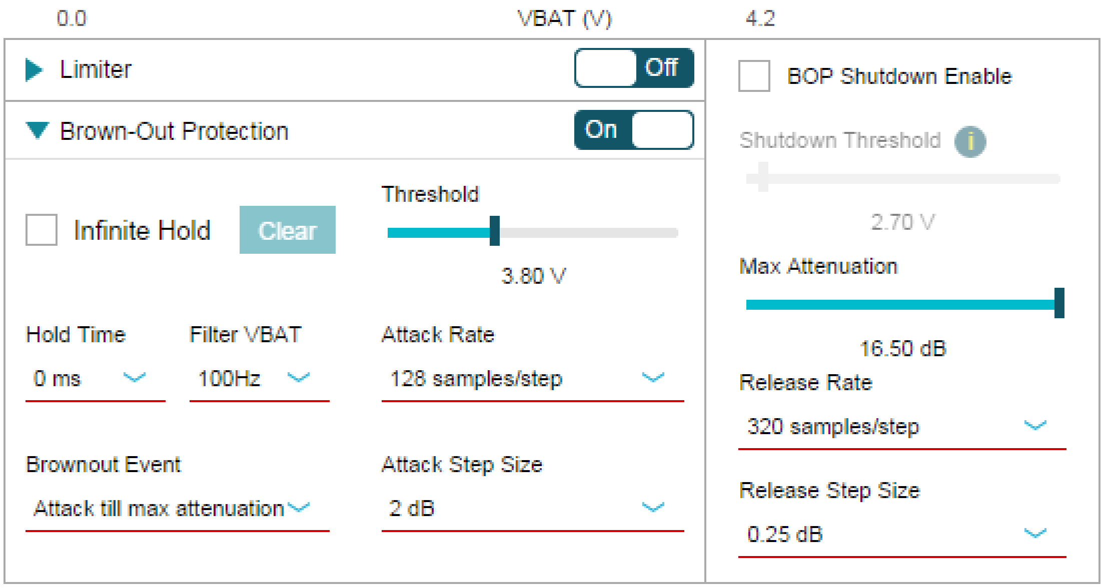



**Figure 12. Limiter Pumping PPC3 Settings**

To change this behavior, the hold time was set to 500 ms, VBAT filtering was set to a higher frequency, Attack step size was changed from 2 dB to 0.5 dB, and maximum attenuation was set to just 5.5 dB. Additionally, the release speed was increased significantly.

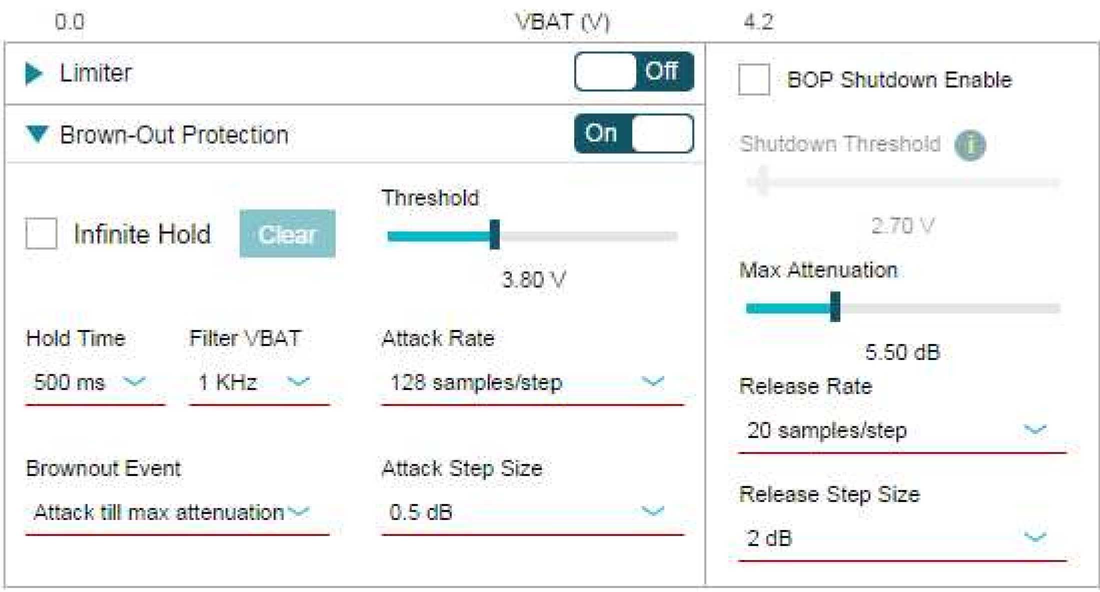
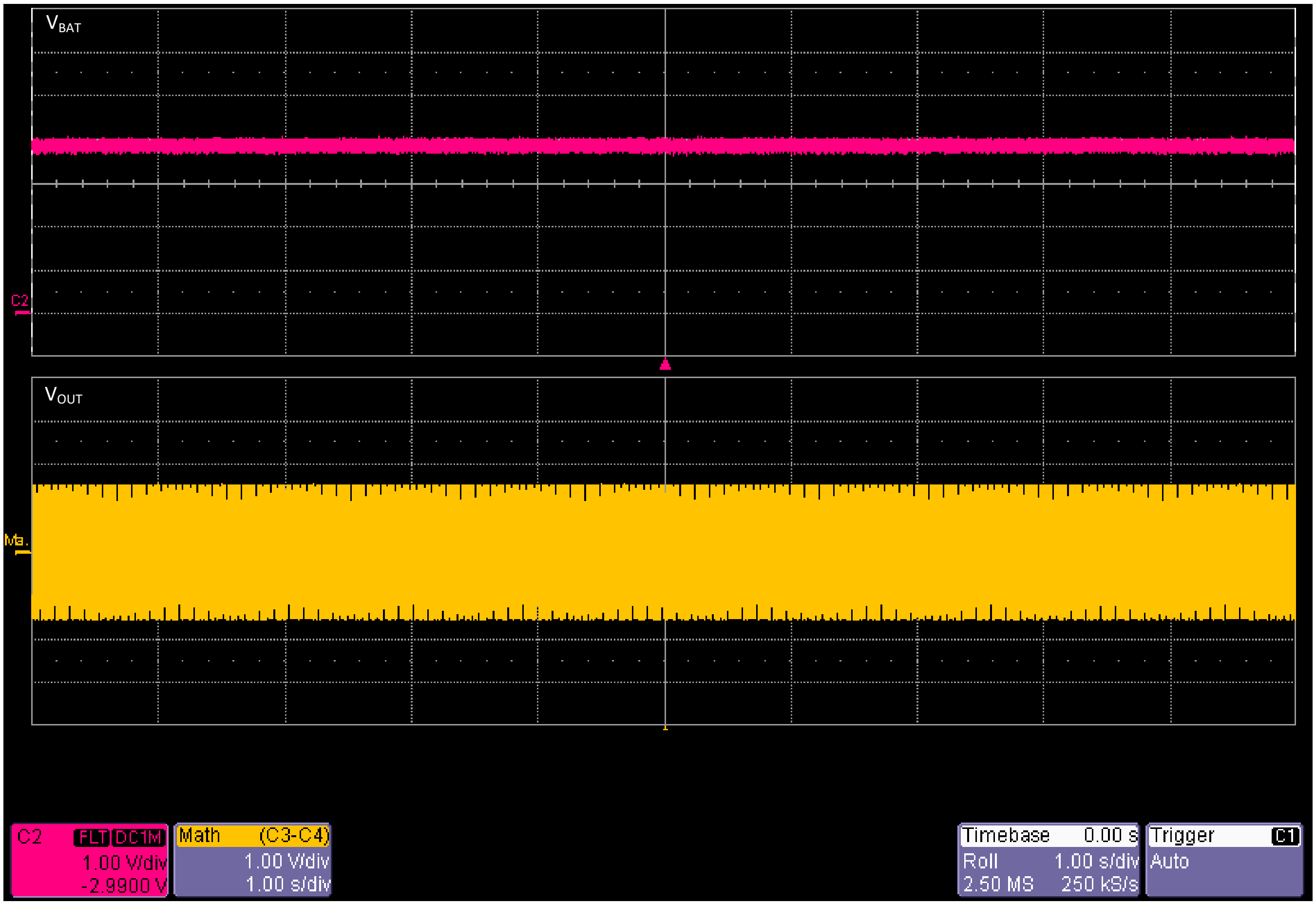



**Figure 13. Fixed PPC3 Settings**

With the settings in Figure 13 notice the new behavior with input and supply conditions unchanged.




Now the output remains at a constant level while the attack is active. We still gain the benefit of the attenuation, but the output level is now steady.

## 8 References


- TAS2562 Datasheet
- TAS2563 Datasheet
- TAS2770 Datasheet

## IMPORTANT NOTICE AND DISCLAIMER