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# Variable Attenuator Repeatability

Quantification and mitigation of the effects of hysteresis on the variable attenuator

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# 1 CONTENTS

# 2 INTRODUCTION

The two primary technologies used for electronically tunable attenuation in the mm-wave are PIN diode and rotary vane. Micro Harmonics has developed a third approach that uses the principle of Faraday rotation to rotate the RF signal polarity into a fixed resistive vane. There are no moving parts and no sensitivity to electrostatic discharge. Micro Harmonics' voltage variable attenuator (VA) is controlled using a DC voltage supply. The DC voltage sets the current in the magnetic coil, which controls the magnetic bias field. **The purpose of this application note is to explain how the repeatability of the attenuation level is affected by various methods used to control the variable attenuator.**

Hysteresis is the primary detractor from the repeatability of the VA. In short, the voltage variable attenuator "remembers" its history. That is, the ferrite core is subject to residual magnetization based on the strength of the field generated from the electromagnetic coil surrounding it. Therefore, the exact attenuation level is a function of the current control voltage *and the history of the control voltage*. Though the phenomenon of hysteresis has useful applications, for the purpose of the variable attenuator it is an unavoidable nuisance.

The effect of hysteresis is shown by sweeping the control voltage from 0V to 10V, and then back down to 0V. In this application note only the results from testing performed at 92.5 GHz (middle of W-band) on a VA100 (WR-10 variable attenuator) are shown. Testing results from the W-band VA have demonstrated that the effects of hysteresis are independent of frequency. In Figure 1 the blue trace shows the attenuation as the voltage is swept up, and the gold trace shows the attenuation as the voltage is swept down. The traces mostly overlap. But the effects of hysteresis can be seen where the traces are mismatched. For example, the attenuation is about 20 dB when 1V is applied to the control voltage port. But the attenuation is slightly greater if "approaching" from 0V (blue), and slightly lower if "approaching" from 10V (gold).

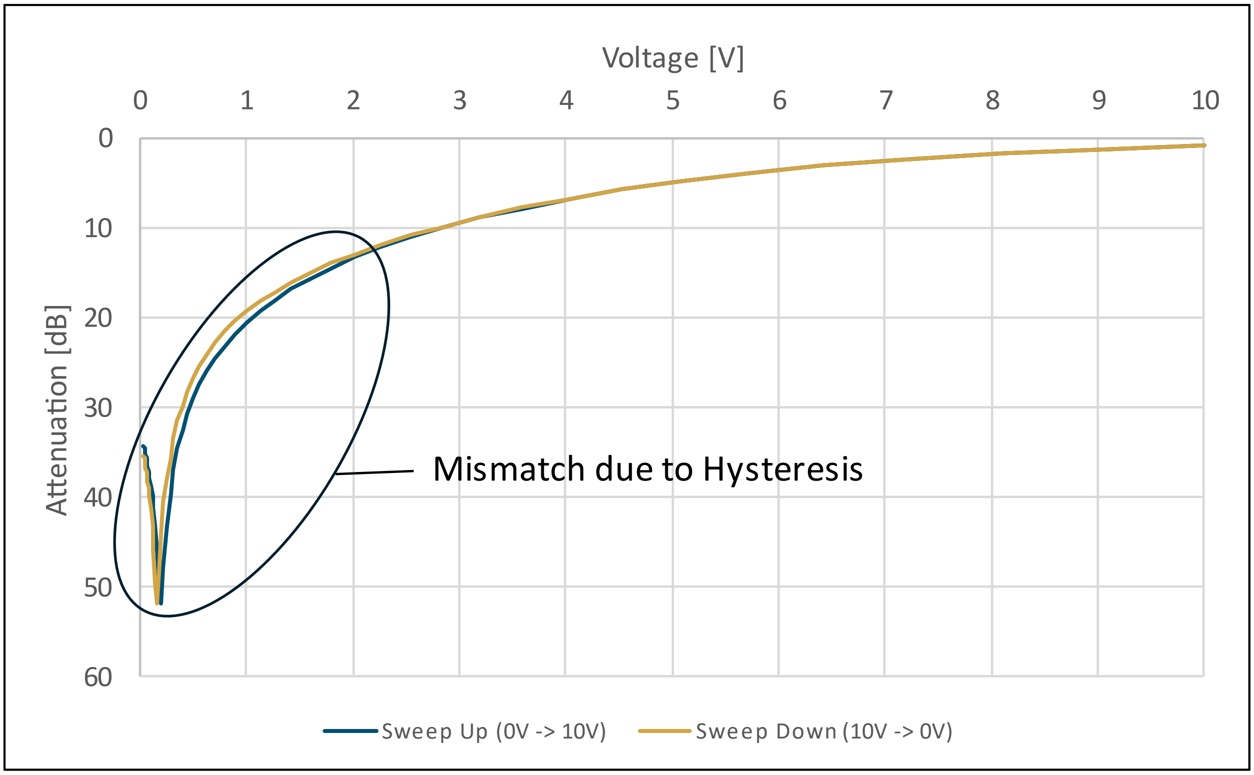


*Figure 1: Effect of hysteresis in variable attenuator demonstrated by control voltage sweeps*

Now that the problem of hysteresis has been shown, the techniques to quantify it and mitigate it can be explored. Hysteresis can be substantially mitigated with control logic used to reset the VA. The basic idea is to make sure that the control voltage "history" is always the same (or at least the same in the ways that matter). When a change to the control voltage would yield inconsistent attenuation results, a standard control voltage is applied to the VA to "reset" the unit first. In cases where repeatability is not as important, control logic can be ignored entirely, and the attenuator is controlled with no regard for the attenuation history (control voltage history).

A good way to explore hysteresis mitigation further is to see different methods for resetting the VA and how they affect repeatability. To show this, a snapshot of the tests used to characterize the effectiveness of these reset methods are presented in Section 3. One test from each reset method will be shown. For each reset method, the control voltage will be swept up and then down. Sweeping the control voltage in both directions from minimum to maximum ensures that the repeatability is measured against the most diverse history. The attenuation of the VA across time as the control voltage is swept is shown in Figure 2. Note that maximum attenuation does not occur at 0V because the ferrite contains remanent magnetization. Also note that the voltage sweep used (not shown) is nonlinear to obtain a more linearized attenuation sweep across time.

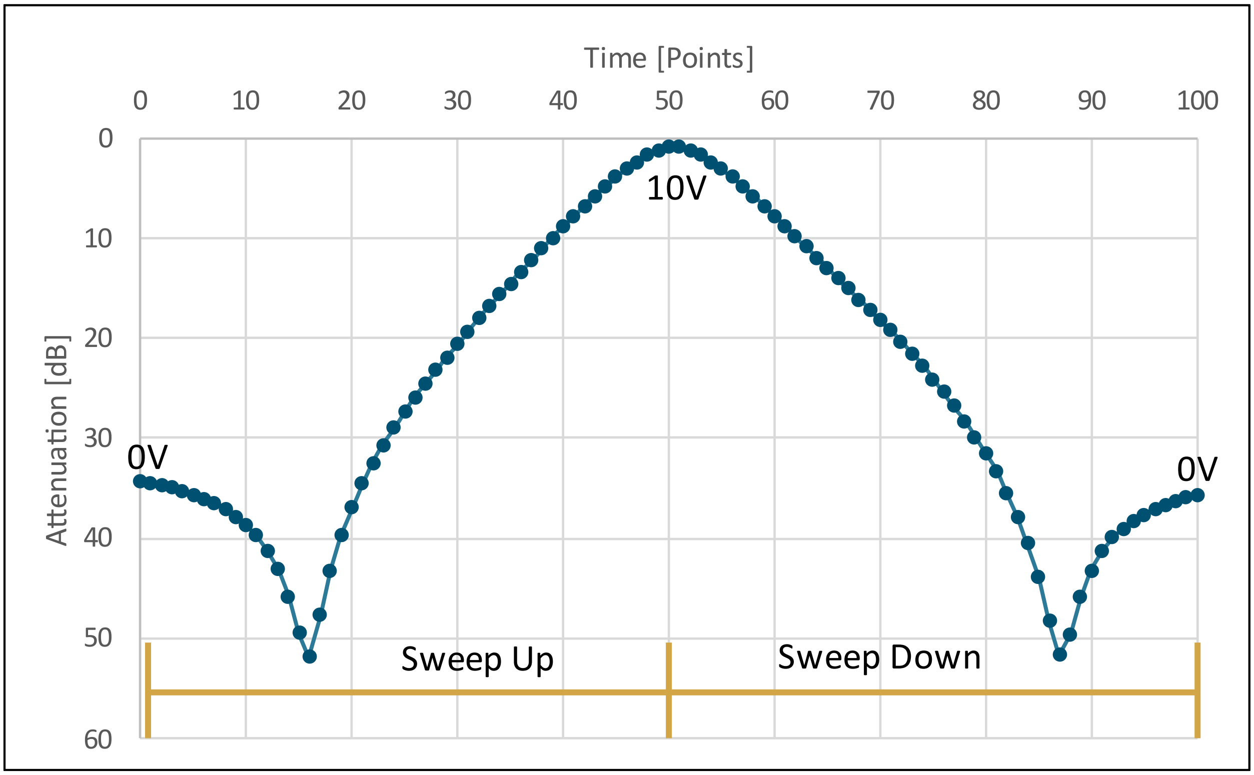


*Figure 2: Attenuation of the variable attenuator at 92.5 GHz over time as control voltage is swept up and down*

# 3 RESET METHODS

For each reset method a trial voltage is selected. For the examples in this application note, the trial voltage is 0.87V which yields about 20 dB attenuation for this particular voltage variable attenuator (VA) at 92.5 GHz (as observed in Figure 1). The idea is to see how much variation in attenuation occurs when applying a consistent trial voltage of 0.87V, as the history of the control voltage differs. The voltage sweep demonstrated in Figure 2 is used to simulate the full gamut of control voltage possibilities.

## 3.1 No Reset

The data in Figure 3 was generated by applying the trial control voltage to the VA between each sweep step. It can be observed that the attenuation achieved *by the same trial voltage* shifts down as the attenuation sweep passes through the attenuation level reached by the trial voltage. In other words, the attenuation achieved by a given trial voltage shifts down as the voltage sweeps higher than the trial voltage. The same phenomenon is observed for the down sweep. Depending on the history (the sweep voltage), the trial voltage might yield 20 dB attenuation or 21 dB attenuation or somewhere in between.

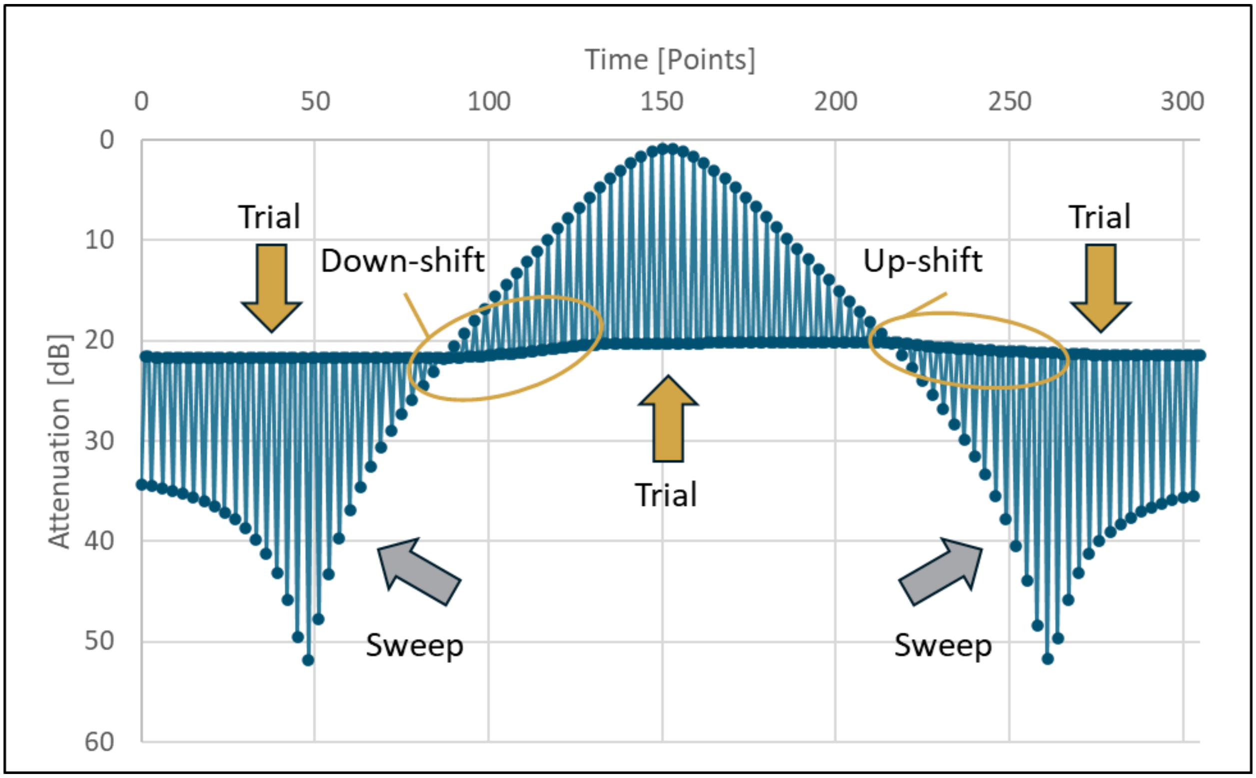


*Figure 3: Example of testing repeatability of the variable attenuator at 20 dB using the no reset method*

Using the no reset method, as demonstrated, yields the least repeatable results. But it has the advantage of requiring no additional control logic.

## 3.2 Reset @ 10 Volts

The reset @ 10V method resets the VA by applying 10V to the control circuit before applying the trial voltage. The order of operation for the repeatability test is to apply the voltages as such:

1. sweep voltage
2. reset voltage (10V)
3. trial voltage (0.87V for the experiments shown in this application note)
4. Repeat 1-3 for next sweep voltage step

Because the reset voltage is applied immediately before the trial voltage, the most immediate history of the VA is always consistent. This technique largely mitigates the inconsistency from hysteresis because the immediate history is fixed at 10V. It can be seen from Figure 4 that the trial voltages now consistently yield almost a perfect 20 dB attenuation, even though the variable attenuator was still swept from 0V to 10V and back to 0V.

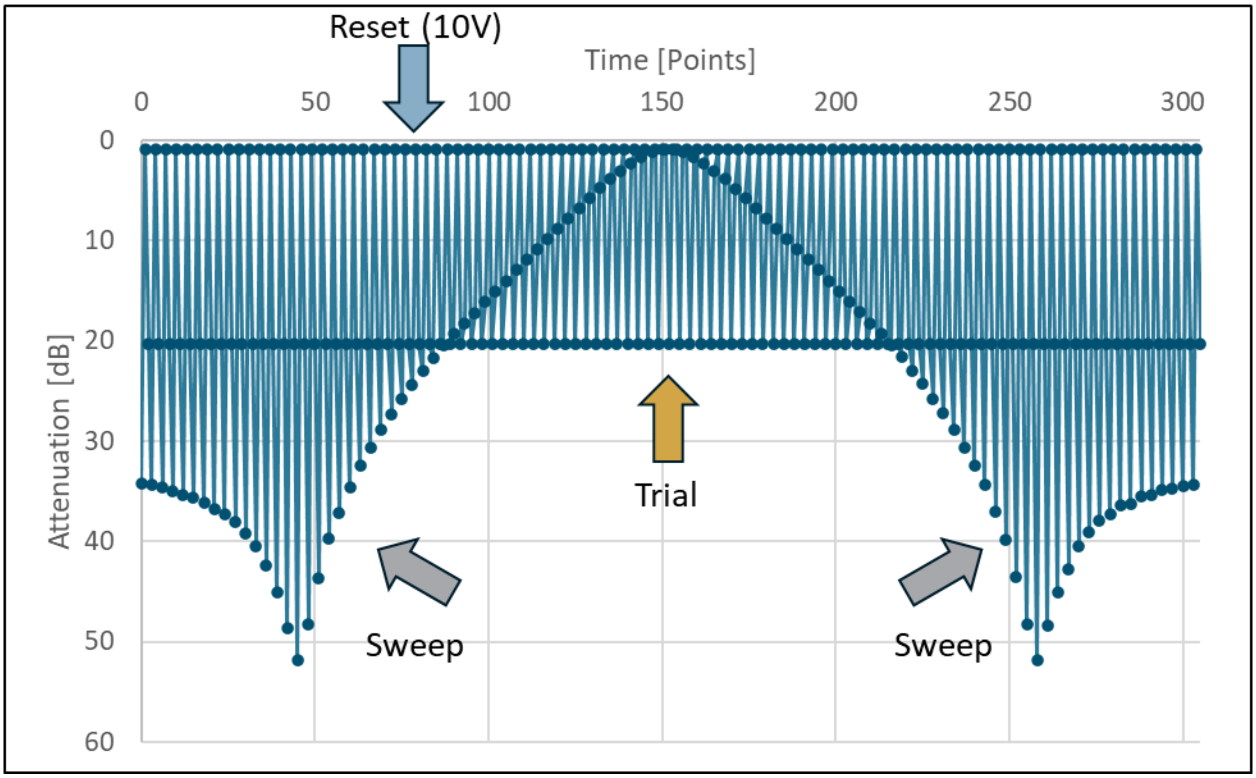


*Figure 4: Example of testing repeatability of the variable attenuator at 20 dB using the reset @ 10V reset method*

Resetting at 10V, as demonstrated, yields the best repeatability. But it has the disadvantage of requiring additional control logic. A second, more subtle disadvantage is that resetting at 10V will temporarily set the attenuator to nominally zero dB attenuation (i.e., the insertion loss). This might be unacceptable depending on the system requirements.

## 3.3 Reset @ 0 Volts

The reset @ 0V method is the exact same as the reset @ 10V method except that the VA is reset by applying 0V to the control circuit instead of 10V. The order of operation for the repeatability test is the same:

1. sweep voltage
2. reset voltage (0V)
3. trial voltage (0.87V for the experiments shown in this application note)
4. Repeat 1-3 for next sweep voltage step

Resetting at 0V also largely mitigates the inconsistency from hysteresis because the history is always fixed at 0V. It can be seen from Figure 5 that the trial voltages now consistently yield almost a perfect 21 dB attenuation, even though the variable attenuator was still swept from 0V to 10V and back to 0V. Note that as expected the attenuation level resulting from a trial voltage of 0.87V is different between resetting at 10V (Figure 4) and 0V (Figure 5).

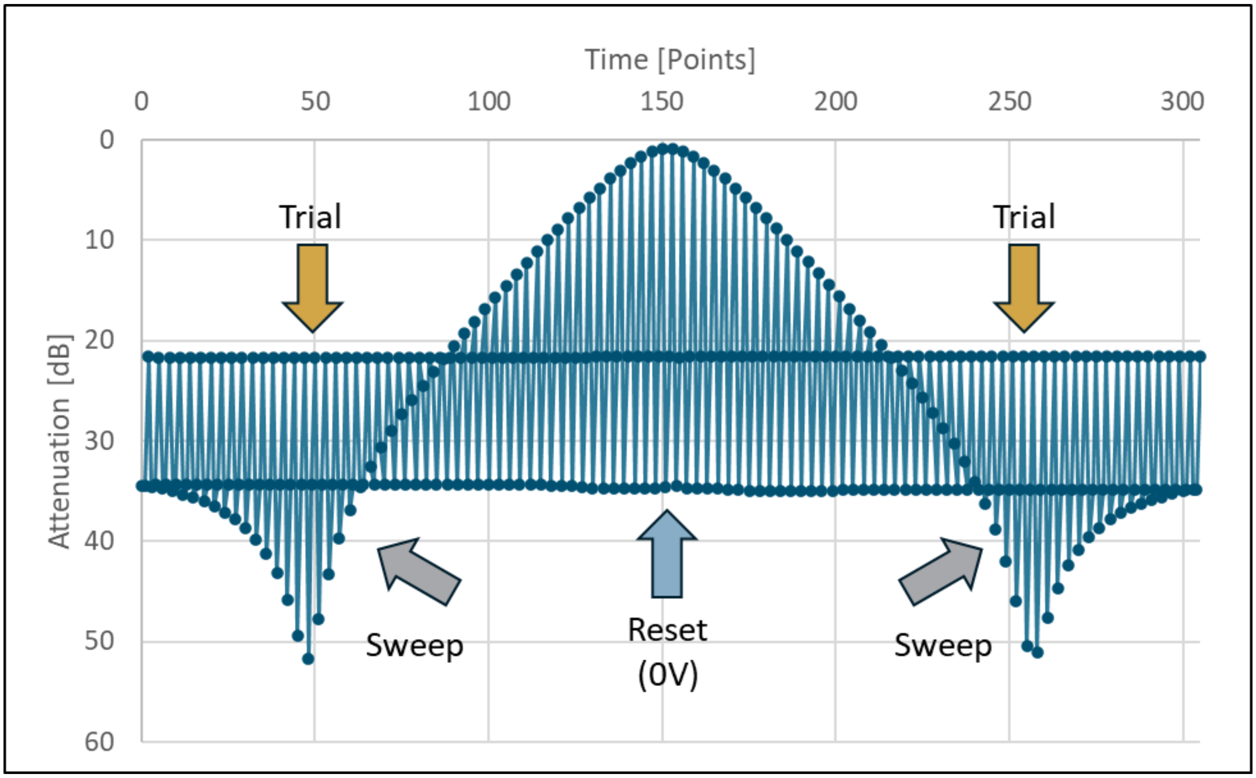


*Figure 5: Example of testing repeatability of the variable attenuator at 20 dB using the reset @ 0V reset method*

Resetting at 0V, as demonstrated, yields great repeatability. But it has the disadvantage of requiring additional control logic. Though it is not discernible from Figure 4 or Figure 5, it is interesting to note that resetting at 10V yields a slightly better repeatability than resetting at 0V. Resetting at 0V, however, does not generate risk since the attenuation achieved at 0V is usually about 35 dB, which is the highest level of attenuation specified for the VA.

## 3.4 Reset @ X Volts

It should be mentioned that any arbitrary voltage within the allowable control voltage range can be used to reset the VA. *However, for the reset to be helpful, it must always be either the highest or lowest voltage used for the given test scenario*. For example, 2V could be used as the reset voltage for the variable attenuator if the control voltage range is constrained to 0-2V *or* 2–10V for a given experiment.

# 4 Monotonic Sweep

Now that the reset methods are understood, the topic of monotonic sweeps can be addressed. It is true that between every voltage adjustment the VA can be reset using a particular control voltage (normally 0V or 10V). However, depending on the application *it's possible to reduce the number of times the VA needs to be reset without sacrificing repeatabili*ty. After resetting the VA to a particular upper or lower control voltage bound, the control voltage can be adjusted from that bound monotonically with no reset required between control voltage levels. The repeatability achieved by resetting between each control voltage level and only at the beginning of a monotonic sweep is the same. This is true regardless of the time between control voltage levels or the step sizes between the levels. The time and voltage step sizes can be chaotic, and yet the repeatability will be unaffected for a monotonic sweep.

# 5 Conclusion

Though hysteresis is a nuisance when it comes to repeatability for the variable attenuator, adding additional control logic to reset the variable attenuator can drastically improve the repeatability. Additionally, the variable attenuator does not need reset during a monotonic sweep, but only when the control voltage is adjusted non-monotonically. Though not discussed, the repeatability is dependent on the attenuation level; the variable attenuator decreases in repeatability as attenuation increases. A summary graphic of the repeatability for different reset methods at different levels of attenuation is provided in Figure 6.

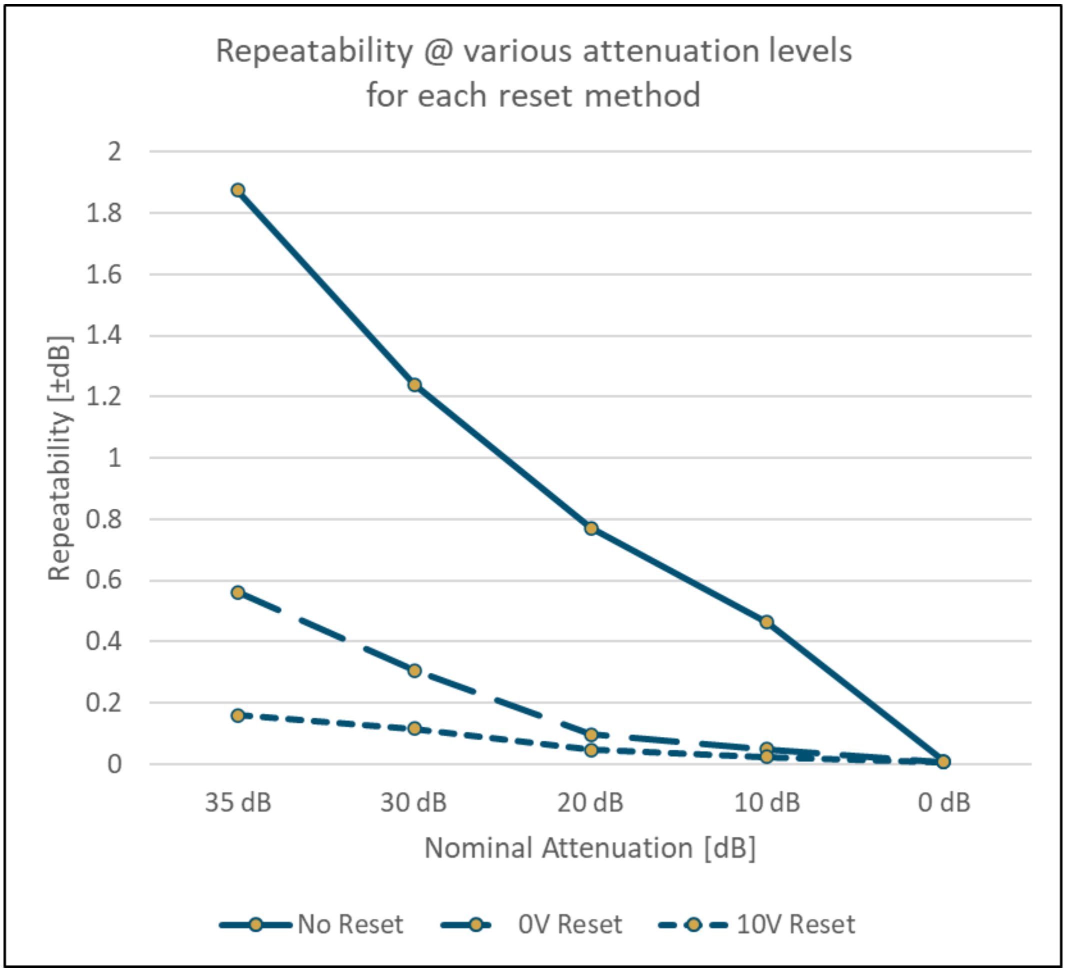


*Figure 6: Summary chart showing repeatability of WR-10 variable attenuator at different levels of attenuation for the three main reset methods*

The advantages and disadvantages of each repeatability method are summarized in Table 1 below.

*Table 1: Summary of the advantages and disadvantages of the three reset methods*

| *Reset Method* | *Repeatability* | *Requires Additional Control Logic* | *Risk* |
| --- | --- | --- | --- |
| ***No Reset*** | Worst | No | None |
| ***Reset @ 10V*** | Best | Yes | 0 dB attenuation during reset |
| ***Reset @ 0V*** | Good | Yes | None |