

Application Note AN6005

APVSG Additive White Gaussian Noise

Purpose

The APVSG devices can optionally be equipped with an additive white gaussian noise generator (AWGN). This option is useful for simulating and testing purposes that require noisy channels, with a controlled carrier to noise ratio. This application note presents the implemented concept and configuration options of the AWGN.

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Introduction

The additive white gaussian noise¹ (AWGN) is an option with which the APVSG devices can be equipped. It allows the user to add noise to the generated output of the device in a controlled manner.

The additive property of the AWGN can either be applied to add the noise to a carrier frequency signal, or to an activate modulation signal. The impact of the noise is then controlled by setting the carrier to noise ratio whilst keeping the total output power of the device constant.

Furthermore, the bandwidth of the AWGN is adjustable to values up to 400 MHz. In case of combining the AWGN with other modulations, the noise bandwidth depends on the playback rate of the enabled modulation.

This application note first gives a quick introduction for the user to get started right away. It then describes the different concepts behind each of the main SCPI commands for the AWGN feature. These commands are listed here for your convenience.

BB:AWGN[:STATe] ON|OFF|1|0

Enable/Disable the use of the AWGN.

BB:AWGN:CNR <dB>

Set the power carrier to noise ratio (CNR) to a fractional number between -70dB and 100dB.

BB:AWGN:BANDwidth <freq>

Set the bandwidth of the noise, if there is no other modulation enabled.

BB:AWGN:POWer:CONTRol TOTAL|CARRier|NOISe

Sets the power control mode for a device with active AWGN.

BB:AWGN:POWer:CARRier <float>

Sets the total carrier power for a device with active AWGN.

BB:AWGN:POWer:NOISe <float>

Sets the total noise power for a device with active AWGN.

Further related documentation is:

- Programmer's Manual [1]
with a description of all SCPI commands
- APVSG Datasheet [2]
with specifications on the APVSG devices.
- AN6003 [3]
with explanations on storing and playing segments and sequences to/from the memory.

¹ The noise is classified as additive white gaussian noise with the following properties.

- The probability density function (PDF) of its amplitude is equal to the gaussian distribution.
- The PDF holds the properties $\mu = 0$, $\sigma^2 = 1$
- The power spectral density is constant.

Quick Start

Provided that the AWGN option is included in your APVSG device, you can have white gaussian noise added to a modulation. For the additive noise, the carrier to noise ratio (CNR) that determines the total carrier power to total noise power ratio must be set in dB, according to

$$CNR[dB] = 10 \cdot \log_{10} \frac{P_{C,tot}[W]}{P_{N,tot}[W]}$$

Setting the CNR will not change the output power of the device, but rather adjust the carrier, noise and total powers individually to meet the specified CNR. Section *Power Control Mode* describes how to keep one of these power values constant while the CNR changes. The set CNR factor determines the multiplier for the modulation data and noise before being summed up to then modulate the carrier. This dependency is illustrated in *Figure 1*.

With active modulation data, the bandwidth of the noise is dictated by the playback rate (PBR).

$$f_{BW,N} = 0.8 \cdot f_{PBR}$$

When applying modulation data, the playback rate must match the data sampling rate.

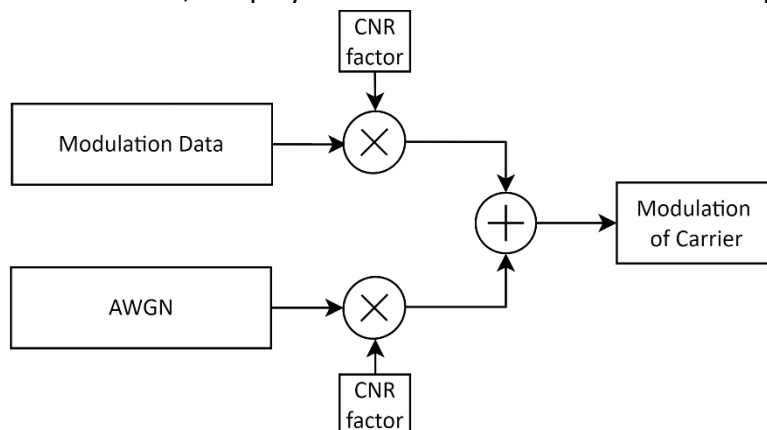


Figure 1: Simplified functional diagram of modulation and AWGN. Inconsequential parts and options are omitted for readability.

Example

The following is a full example for setting up the APVSG with

- A carrier frequency of 1 GHz
- Modulated with a 100 MHz 1-tone
- AWGN with an CNR of 20 dB
- 250 MHz playback rate and 250 MHz noise bandwidth

Complete SCPI command sequence:

FREQ 1e9	Set initial RF output frequency
OUTP:STAT ON	Enable RF output
BB:ARB:CLOC 250e6	Set the playback rate (= sample rate of mod. data)
BB:ARB:WAV:DATA 0 <data>	Upload <data> block to segment 0 of the memory
BB:ARB:WSEG 0	Select segment 0 for replay
BB:ARB:WAV:STAT ON	Enable IQ Modulation (from segment 0)
BB:AWGN:CNR 20	Set CNR ratio to 20 dB
BB:AWGN:STAT ON	Enable AWGN

Power Declarations

Carrier Power

The variable $P_{C,tot}$ describes the total carrier power at the output of the device. It is the RMS value, assumed the carrier is a single frequency sine wave.

Please note that this is not necessarily the actual total signal power at the output. The total signal power depends on the active modulation.

Noise Power

$P_{N,tot}$ denotes the total RMS noise power at the output of the device. The corresponding noise density naturally depends on the momentary noise bandwidth.

Output Power

The set power at the RF output is defined as the total RMS power, consisting of the total RMS carrier power and the total RMS noise power.

$$P_{out,tot}[W] = P_{C,tot}[W] + P_{N,tot}[W]$$

Carrier to Noise Ratio

BB:AWGN:CNR <dB>

Set the power carrier to noise ratio (CNR) as a fractional value between -70dB and 100dB.

Be advised that the output power at the RF out connector of the device might show a short peak in power while switching CNR or any of the power levels. During this short peak the output can drive up to 21dB more total power than the actual device setting. This only applies if the AWGN is active.

Concept

The carrier to noise ratio set with the SCPI command is in respect to the total power of both the carrier and noise.

$$CNR[dB] = 10 \cdot \log_{10} \frac{P_{C,tot}}{P_{N,tot}} = 20 \cdot \log_{10} \frac{A_{C,rms}}{A_{N,rms}}$$

The signal generator accounts for the root mean square of the amplitude of each signal. The maximal amplitude of both the carrier and the noise is adjusted to produce an accurate power ratio at the RF out of the APVSG.

The root mean square values of the amplitude for the carrier and noise are related to the maximal amplitude as follows

$$A_{C,rms} = \frac{1}{\sqrt{2}} \cdot A_{C,max}, \quad A_{N,rms} = \frac{1}{16} \cdot A_{N,max}$$

Modulated Signal to Noise Ratio

If the modulation used on the signal deviates from a simple sine wave, the RMS value of the modulation must be accounted for when setting the CNR.

Let's assume the RMS amplitude of the modulated signal is

$$A_{Signal,rms} = x \cdot A_{C,rms} = \frac{x}{\sqrt{2}} \cdot A_{C,max}$$

The desired signal to noise ratio is then defined by

$$SNR = 10 \cdot \log_{10} \frac{P_{Signal,tot}}{P_{N,tot}} = 20 \cdot \log_{10} \left(x \cdot \frac{A_{C,rms}}{A_{N,rms}} \right) = CNR + 20 \cdot \log_{10}(x)$$

Therefore, please make sure to adjust the set CNR according to the amplitude $A_{Signal,rms}$ of the applied modulation data.

Step Size

The CNR has a logarithmic dependency to the amplitude of the carrier and noise and therefore the accuracy of the set CNR value is not linear across the full range of possible values.

The actual step sizes of the CNR are plotted in *Figure 2*. However, the CNR can be set reliably with an accuracy of 0.01dB in the range between -20dB and 50dB.

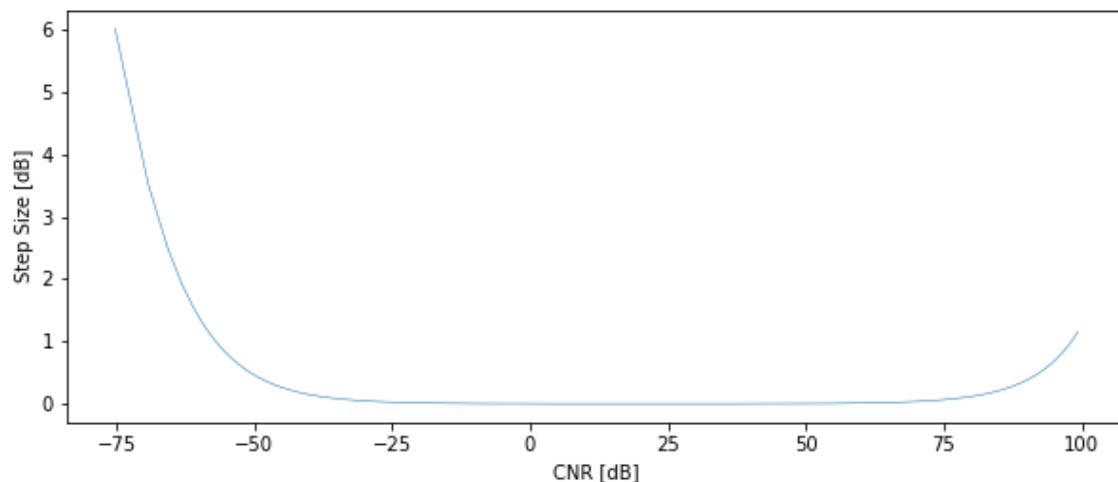


Figure 2: Step size of the carrier to noise ratio.

Noise Bandwidth

The bandwidth of the AWGN is set explicitly when there is no modulation enabled. The respective SCPI command is described below.

Apart from that, the noise bandwidth is always automatically set depending on the playback rate (PBR).

$$f_{BW} = 0.8 \cdot f_{PBR}$$

Table 1 lists the different modulation and AWGN state options and provides the SCPI command to set the playback rate and/or AWGN bandwidth in each case. The table also indicates which of the two are impacted with each respective command.

Please be advised that the spectrum of the generated AWGN is always centered around the carrier frequency and can never be more than a maximum of 400 MHz.

SCPI Command

BB:AWGN:BANDwidth <freq>

Set the bandwidth of the noise, if there is no other modulation enabled.

BB:ARbitrary:CLOCK <freq>

Set the playback rate in Hz. For a modulation with additive noise, this is the sampling rate of the modulation, as well as the bandwidth of the noise.

Power Control Mode

AWGN Power SCPI Commands

BB:AWGN:POWer:CONTRol TOTal|CARRier|NOISe

Sets the power control mode for a device with active AWGN.

BB:AWGN:POWer:CARRier <float>

Sets the total carrier power $P_{C,tot}$ for a device with active AWGN.

BB:AWGN:POWer:NOISe <float>

Sets the total noise power $P_{N,tot}$ for a device with active AWGN.

Power Control Concept

When the device is in a state where AWGN is active, the user has several different options on how to control the various power values. At any given point in time, the power variables will have the following dependencies.

$$CNR = P_{C,tot}[\text{dBm}] - P_{N,tot}[\text{dBm}], \quad P_{out,tot}[\text{W}] = P_{C,tot}[\text{W}] + P_{N,tot}[\text{W}]$$

For declarations of the individual variables, please consult section *Power Declarations*.

The chosen power control mode dictates the behavior of the power variables whenever the CNR or one power setting changes. The different power control modes are explained hereafter.

Total Power Control Mode

Putting the device into total power control mode lets the total RF output power stay constant for any constant modulation, while the CNR is changing. When AWGN is active, this mode can be set with the SCPI command

- **BB:AWGN:POWer:CONTRol TOTal**

Setting either the CNR factor or $P_{out,tot}$ results in a change of $P_{C,tot}$ and $P_{N,tot}$ to achieve the set values for both CNR and $P_{out,tot}$.

The power at the output of the device is set with the SCPI command

- **POWer[:LEVel][:IMMEdiate][:AMPLitude] <float>**

$P_{C,tot}$ and $P_{N,tot}$ cannot be set in this mode, but their values can be read with the corresponding SCPI commands.

The maximum and minimum of CNR might be capped in the total power control mode if the current setting of the output power requires it.

Carrier Power Control Mode

A constant carrier power at the RF output during operation with AWGN can be achieved by setting the APVSG into carrier power control mode. The mode then ensures a constant carrier power at the output while the CNR value changes. To set this mode, the following SCPI command must be utilized.

- **BB:AWGN:POWer:CONTRol CARRier**

Setting either the CNR factor or $P_{C,tot}$ results in a change of $P_{out,tot}$ and $P_{N,tot}$ to achieve the set values for both CNR and $P_{C,tot}$. The total RMS signal power will therefore stay constant for any constant modulation.

The carrier power is set with the SCPI command

- **BB:AWGN:POWer:CARRier <float>**

Setting either $P_{out,tot}$ (or $P_{N,tot}$) results in a change of $P_{C,tot}$ as well as $P_{N,tot}$ (or $P_{out,tot}$) to keep CNR at its set value.

Noise Power Control Mode

Activating the noise power control mode allows the user to keep the total noise power of the AWGN constant. For a static noise bandwidth² this naturally results in a constant noise density. In this mode, the total noise power therefore stays constant when the CNR changes. The related SCPI command is

- **BB:AWGN:POWer:CONTRol NOISe**

Setting either the CNR factor or $P_{N,tot}$ results in a change of $P_{out,tot}$ and $P_{C,tot}$ to achieve the set values for both CNR and $P_{N,tot}$. The noise power is set with the SCPI command

- **BB:AWGN:POWer:NOISe <float>**

Setting $P_{out,tot}$ (or $P_{C,tot}$) results in a change of $P_{N,tot}$ as well as $P_{C,tot}$ (or $P_{out,tot}$) to keep CNR at its set value.

² For a description of the dependency between the noise bandwidth and the modulation playback rate, please consult section *Noise Bandwidth*.

Additive Modulation Concept

Activating Modulation

As depicted in *Figure 1*, the activated parts (AWGN and Modulation) are multiplied with a factor depending on the set CNR and then added up to modulate the carrier. The AWGN and modulation data can each separately be switched on and off with the following SCPI commands.

- **BB:AWGN[:STATE] ON|OFF|1|0**
Enable/Disable the use of the AWGN.
- **BB:ARB:WAV:STATE ON|OFF|1|0**
Enable/Disable the IQ modulation from memory. See AN 6003 [3] for further information.

Modulate AWGN or Modulation Data

Whenever only one of the two is enabled, the APVSG automatically sets the multiplication factors, such that the resulting modulation of the carrier frequency is as expected. These two operation options are depicted below. *Figure 3* shows how the AWGN is completely ignored whilst the modulation data is directly forwarded, in case only the modulation is active and the AWGN is disabled.

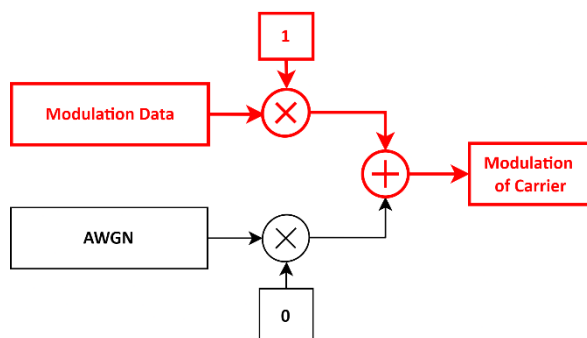


Figure 3: Modulation enabled and AWGN disabled.

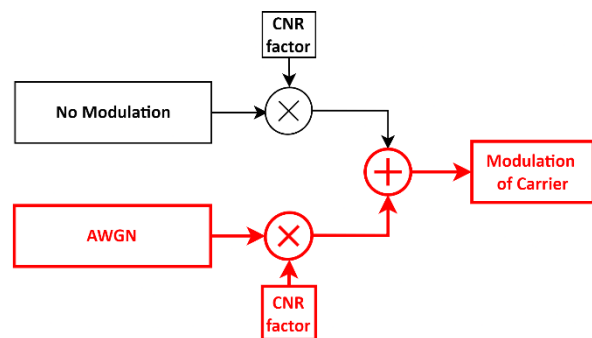


Figure 4: Modulation disabled and AWGN enabled.

For the opposite case, which is illustrated in *Figure 4*, there is no modulation present. However, the CNR is utilized to produce a correct power ratio between carrier and the generated AWGN. Please also read section *Noise Bandwidth* to learn how to set the generated frequency band of the noise, centered around the carrier frequency. The noise bandwidth can only be set in this specific operation mode.

Extended Modulation Overview

The modulation deployed along with AWGN is typically a digital modulation which is stored in the internal memory of the device and replayed therefrom. Have a look at the APVSG graphical user interface (GUI) to get an overview of the possible modulation options that can be stored on the device. For more information on storing and replaying modulation data, consult AN6003 [3].

If your APVSG includes the FCP option, streaming IQ data is possible by enabling the FCP IQ modulation and replacing BB:ARB:WAV:STAT with the following command. As with other modulation data, this IQ data can be used for modulation along with the AWGN option.

- **BB:ARB:FCP[:STATe] ON|OFF**
[option] Enable/disable IQ modulation stream from FCP interface.

Figure 5 and the following table give a description for the possible modulations from the different sources, combined with AWGN.

Table 1: Modulation options with their attributes and impact on the output.

Modulation State	Modulation Factor	AWGN	Playback Rate	Output
BB:ARB:WAV:STAT OFF BB:ARB:FCP:STAT OFF BB:AWGN:STAT OFF	1	None	None	Carrier
BB:ARB:WAV:STAT OFF BB:ARB:FCP:STAT OFF BB:AWGN:STAT ON	1	CNR dependent	BB:AWGN:BAND Noise BW	Carrier & AWGN
BB:ARB:WAV:STAT ON BB:ARB:FCP:STAT OFF BB:AWGN:STAT OFF	1	None	BB:ARB:CLOC Sampling Rate	Modulation
BB:ARB:WAV:STAT ON BB:ARB:FCP:STAT OFF BB:AWGN:STAT ON	CNR dependent	CNR dependent	BB:ARB:CLOC Sampling Rate & Noise BW	Modulation & AWGN
BB:ARB:WAV:STAT OFF BB:ARB:FCP:STAT ON BB:AWGN:STAT OFF	1	None	BB:ARB:CLOC FCP Rate	FCP Modulation
BB:ARB:WAV:STAT OFF BB:ARB:FCP:STAT ON BB:AWGN:STAT ON	CNR dependent	CNR dependent	BB:ARB:CLOC FCP Rate & Noise BW	FCP Mod. & AWGN
BB:ARB:WAV:STAT ON BB:ARB:FCP:STAT ON BB:AWGN:STAT <x>	Illegal setting (FCP and IQ modulation must not be active simultaneously)			

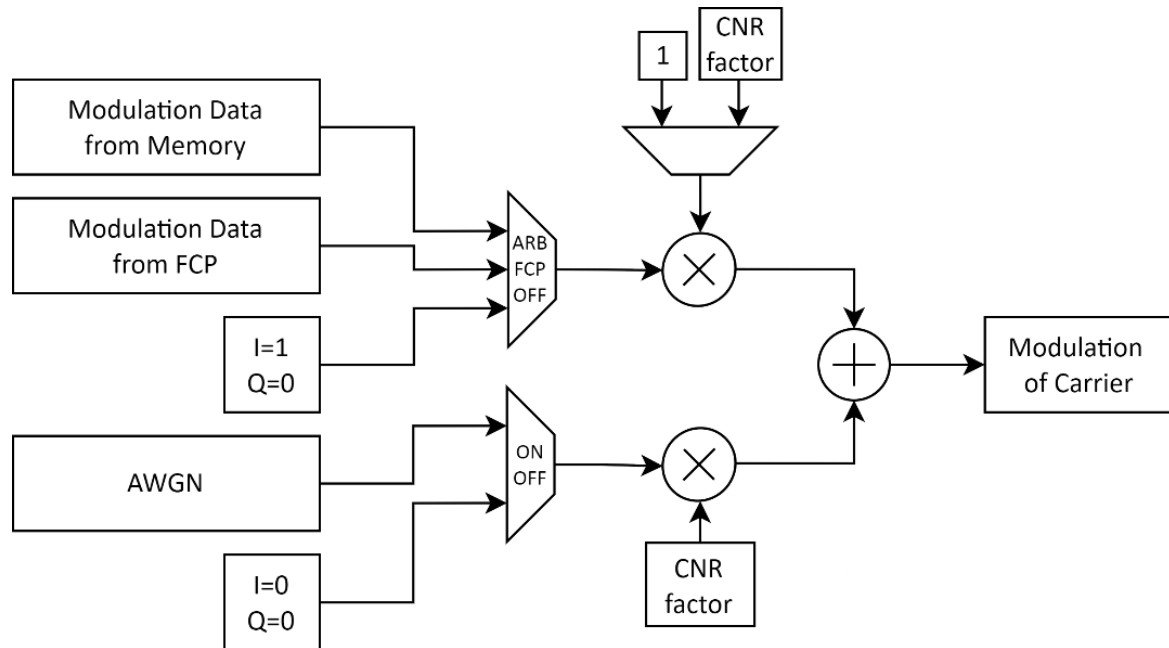


Figure 5: Extended graphic on AWGN and modulation options from various sources.

Further Documentation

- [1] AnaPico Programmer's Manual for Signal Generators
<https://www.anapico.com/downloads/manuals/>
Includes description of all SCPI commands.
- [2] APVSG Datasheet
<https://www.anapico.com/downloads/brochures-and-data-sheets/>
Specifications of APVSG devices
- [3] AN6003 APVSG Memory Segmentation
<https://www.anapico.com/downloads/application-notes-and-videos/>
Description on storing to and replaying from the memory.