# # Generates Gaussian noise with proper variance

noise\_variance = power / 10

noise = np.random.normal(0, np.sqrt(noise\_variance), num\_bits) # Proper scaling of noise

## **Understanding Noise Variance and Its Role in Signal-to-Noise Ratio (SNR)**

The code snippet you provided deals with Gaussian noise generation, an essential aspect of real-world communication systems. Let's break it down **step by step** and explain **why** you are doing this, how it affects the signal-to-noise ratio (SNR), and its real-world applications.

### 1. What Does This Code Do?

noise\_variance = power / 10 # Adjusting the noise variance noise = np.random.normal(0, np.sqrt(noise\_variance), num\_bits) # Proper scaling of noise

• Step 1: Defines the variance of the noise as:

$$\sigma^2 = \frac{\text{power}}{10}$$

• Since power = 10^{-7}, the noise variance is:

$$\sigma^2 = 10^{-7}/10 = 10^{-8}$$

• This means the standard deviation of the noise ( $\sigma$ ) is:

$$\sigma = \sqrt{10^{-8}} = 10^{-4}$$

- Step 2: Generates Gaussian (random) noise with:
  - Mean = 0 (centered around zero, which is common in thermal noise models).
  - Standard deviation =  $\sqrt{\text{noise variance}}$  to ensure correct power scaling.
  - Size = num\_bits (1000 values), meaning each transmitted bit gets affected by independent

## 2. Why Are You Doing This?

A. Modeling Real-World Noise (Additive White Gaussian Noise - AWGN)

- In real-world communication channels, signals experience random fluctuations due to:

  - Thermal noise from direct composerns.
     Atmospheric interference in wireless systems.
- The most common model for this noise is Additive White Gaussian Noise (AWGN):

$$y = x + n$$

- x = transmitted signal (e.g., 0 or  $\sqrt{10^{-7}}$ ).
- n = Gaussian noise with mean 0 and variance  $\sigma^2$ .
- y = received signal after noise addition.

By defining noise\_variance = power / 10 , you are controlling the intensity of noise in your

# B. Impact on Signal-to-Noise Ratio (SNR)

The Signal-to-Noise Ratio (SNR) is a key performance measure in communication systems, defined as:

$$SNR = rac{ ext{Signal Power}}{ ext{Noise Power}}$$

- Signal Power is given as power = 10^{-7}.
- Noise Power is set to noise\_variance = power / 10 = 10^{-8}.

$$SNR = \frac{10^{-7}}{10^{-8}} = 10$$

• In decibels (dB), SNR is computed as:

$$SNR_{dB} = 10\log_{10}(SNR)$$

$$SNR_{dB} = 10 \log_{10}(10) = 10 \text{ dB}$$

This means that your system is designed with an SNR of 10 dB, which is a reasonable level for moderate-quality digital communication.

Yes! If you increase noise\_variance, the noise power increases, reducing the SNR (worse performance). If you decrease noise\_variance, the noise power decreases, improving the SNR.

By choosing power / 10, you are setting a controlled SNR level for your system.

## 3. How Does This Apply to Real Life?

Your noise model is a fundamental part of any real communication system.

### A. Wireless Communication (Wi-Fi, Bluetooth, 5G)

- Higher noise variance (low SNR) leads to more errors, requiring stronger error correction codes.
- Example: A Wi-Fi signal in a noisy environment (many devices) has higher noise variance, meaning lower SNR and possible packet loss.

### B. Space Communication (NASA, Satellites, Deep Space Network)

- Space probes like Voyager, Mars Rovers, and Starlink satellites must deal with extreme noise.
- . Engineers adjust SNR using:
  - Power control (increase transmitter power).
  - Error correction techniques (e.g., Reed-Solomon codes).
  - Antenna design (higher gain antennas increase signal strength).

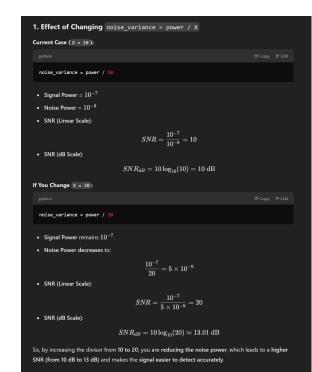
#### C. Audio & Video Transmission

- Digital TV and radio signals have optimized SNR to reduce static and distortion.
- If noise variance is too high, your TV signal might pixelate or audio might cut out.

## D. Radar & Military Systems

- Stealth aircraft (F-35, B-2 bomber) use low radar SNR to remain undetectable.
- Military communication is optimized to maximize SNR, reducing enemy jamming effects.

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# 2. What Happens if You Use a Larger X (e.g., 50, 100)?

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X Value	Noise Variance	SNR (Linear)	SNR (dB)
10	$10^{-8}$	10	10 dB
20	$5  imes 10^{-9}$	20	13 dB
50	$2\times 10^{-9}$	50	17 dB
100	$10^{-9}$	100	20 dB

As x increases, noise power decreases, SNR increases, and fewer errors occur.

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As X increases, noise power decreases, SNR increases, and fewer errors occur.

### 3. What Happens if You Make X Smaller?

Example: Setting X = 5

python

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noise\_variance = power / 5

Noise variance increases to:

$$rac{10^{-7}}{5} = 2 imes 10^{-8}$$

SNR decreases to:

$$SNR = rac{10^{-7}}{2 imes 10^{-8}} = 5$$

SNR (dB Scale):

$$SNR_{dB} = 10 \log_{10}(5) \approx 7dB$$

Now, your signal is harder to distinguish because the noise is stronger, leading to more bit errors.