My Project

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Chapter 1

Telecommunication software engineering - Digital transmitter design and signal modulation

1.1 Project Goal

The goal of this project is to design a basic digital transmitter, focusing on:

- Signal generation,
- Implementation of various modulation techniques,
- Analysis of a communication channel with noise,
- Evaluation of the efficiency and robustness of different modulation schemes.

1.2 Project Description

This project explores the concept of a digital transmitter, how it operates, and how signals are generated and prepared for transmission through a communication channel. It delves into the practical aspects of signal modulation and the challenges of transmitting signals through noisy channels.

1.2.1 Main Activities

1. *Designing a digital transmitter:*
    - Developing a foundational digital transmitter using Python, focusing on modular design and clear signal processing steps.
2. *Implementation of modulation schemes:*
    - Amplitude Modulation (AM),
    - Amplitude Shift Keying (ASK),
    - Frequency Modulation (FM),
    - Frequency Shift Keying (FSK),

- Phase Shift Keying (PSK),
- Binary Phase Shift Keying (BPSK),
- Quadrature Amplitude Modulation (QAM),
- Quadrature Phase Shift Keying (QPSK).

3. *Simulation of a communication channel with noise:*
   - Implementing a channel with Additive White Gaussian Noise (AWGN).
   - Analyzing the Signal-to-Noise Ratio (SNR).
4. *Evaluation of efficiency and robustness:*
   - Assessing the energy efficiency of each modulation scheme.
   - Analyzing noise resistance.

1.3 Repository Structure

Directory name	Description
AM-ASK+tests	This directory contains all code files necessary for AM and ASK modulations, as well as their respective test files.
FM-FSK+tests	This directory contains all code files necessary for FM and FSK modulations, as well as their respective test files.
PSK-BPSK+tests	This directory contains all code files necessary for PSK and BPSK modulations, as well as their respective test files.
QAM-QPSK+tests	This directory contains all code files necessary for QAM and QPSK modulations, as well as their respective test files.
README.md	Project details.

1.4 Modulation techniques

1.4.1 Amplitude Modulation (AM)

Amplitude Modulation (AM) is a modulation technique where the amplitude of the carrier signal is varied in proportion to the instantaneous amplitude of the message signal. It's a simple method but is susceptible to noise.
Amplitude Modulation (AM) image

Figure 1: Amplitude modulation

1.4.2 Amplitude Shift Keying (ASK)

Amplitude Shift Keying (ASK) is a form of amplitude modulation that represents digital data as variations in the amplitude of a carrier wave. In its simplest form, the presence of a carrier wave represents a binary 1, and the absence represents a binary 0.
Amplitude Shift Keying (ASK) image

Figure 2: Amplitude shift keying

1.4.3 Frequency Modulation (FM)

Frequency Modulation (FM) is a modulation technique where the frequency of the carrier signal is varied in proportion to the instantaneous amplitude of the message signal. FM is less susceptible to noise than AM.
Frequency Modulation (FM) image

Figure 3: Frequency modulation

1.4.4 Frequency Shift Keying (FSK)

Frequency Shift Keying (FSK) is a form of frequency modulation that represents digital data as variations in the frequency of a carrier wave. Different frequencies are used to represent different binary values.
Frequency Shift Keying (FSK) image

Figure 4: Frequency shift keying

1.4.5 Phase Shift Keying (PSK)

Phase Shift Keying (PSK) is a modulation technique where the phase of the carrier signal is varied to represent digital data. The amplitude and frequency of the carrier signal remain constant.
Phase Shift Keying (PSK) image

Figure 5: Phase shift keying

1.4.6 Binary Phase Shift Keying (BPSK)

Binary Phase Shift Keying (BPSK) is a form of phase shift keying where the phase of the carrier signal is varied to represent binary data. It uses two phases to represent binary 0 and 1.
Binary Phase Shift Keying (BPSK) image

Figure 6: Binary phase shift keying

1.4.7 Quadrature Amplitude Modulation (QAM)

Quadrature Amplitude Modulation (QAM) is a modulation technique that combines both amplitude and phase modulation to transmit more data per symbol. It uses multiple amplitude levels and phase shifts to encode data.
Quadrature Amplitude Modulation (QAM) image

Figure 6: Quadrature amplitude modulation

1.4.8 Quadrature Phase Shift Keying (QPSK)

Quadrature Phase Shift Keying (QPSK) is a form of phase shift keying where the phase of the carrier signal is varied to represent digital data. It uses four phases to represent two bits of data.
Quadrature Phase Shift Keying (QPSK) image

Figure 7: Quadrature phase shift keying

1.5 Pytest

∗The pytest framework is used to run the tests for each modulation technique. The tests can be run with: ‘pytest -v --cov 'file.py'`.∗
Figure 8 shows how pytest output looks when running the tests for all the modulation techniques:

Figure 8: Code coverage

1.6 Technologies Used

- **Programming Language:** Python

- **Libraries:**

- `numpy` - Numerical data processing.
- `matplotlib` - Visualization of simulation results.
- `scipy` - Noise generation and SNR analysis. .
- `pytest` - Testing framework.
- `coverage` - Code coverage analysis.

Chapter 2

Hierarchical Index

2.1 Class Hierarchy

This inheritance list is sorted roughly, but not completely, alphabetically:

Chapter 3

Class Index

3.1 Class List

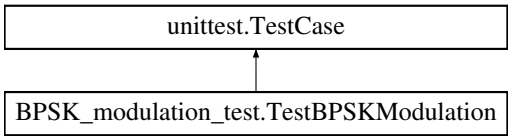
Here are the classes, structs, unions and interfaces with brief descriptions:

Chapter 4

Class Documentation

4.1 BPSK_modulation_test.TestBPSKModulation Class Reference

Inheritance diagram for BPSK_modulation_test.TestBPSKModulation:



Public Member Functions

- test_basic_case (self)
- test_bit_duration (self)
- test_high_frequency (self)
- test_large_binary_data (self)
- test_single_bit (self)
- test_invalid_binary_data (self)
- test_zero_bit_duration (self)
- test_negative_sample_rate (self)
- test_negative_bit_duration (self)
- test_empty_binary_data (self)

4.1.1 Member Function Documentation

4.1.1.1 test_basic_case()

```
BPSK_modulation_test.TestBPSKModulation.test_basic_case (
              self )
```

```
Test the basic functionality of the BPSK modulation function.

Verifies:
- The lengths of all generated signals are consistent.
- The modulating signal corresponds correctly to the binary data input.
```

4.1.1.2 test_bit_duration()

```
BPSK_modulation_test.TestBPSKModulation.test_bit_duration (
              self )
```

```
Test the function with varying bit durations.

Verifies:
- The total duration of the generated signal matches the expected value.
```

4.1.1.3 test_empty_binary_data()

```
BPSK_modulation_test.TestBPSKModulation.test_empty_binary_data (
              self )
```

Test the function with empty binary data.

Verifies:
- The function returns empty arrays when the binary data is empty.

4.1.1.4 test_high_frequency()

```
BPSK_modulation_test.TestBPSKModulation.test_high_frequency (
              self )
```

Test the function with a high carrier frequency.

Verifies:
- The carrier signal is a normalized sine wave with amplitude in the range [-1, 1].

4.1.1.5 test_invalid_binary_data()

```
BPSK_modulation_test.TestBPSKModulation.test_invalid_binary_data (
              self )
```

Test the function with invalid binary input data.

Verifies:
- The function raises a ValueError for non-binary input data.

4.1.1.6 test_large_binary_data()

```
BPSK_modulation_test.TestBPSKModulation.test_large_binary_data (
              self )
```

Test the BPSK modulation function with a large binary data input.

Verifies:
- The function scales appropriately without errors.

4.1.1.7 test_negative_bit_duration()

```
BPSK_modulation_test.TestBPSKModulation.test_negative_bit_duration (
              self )
```

Test the function with a negative bit duration.

Verifies:
- The function raises a ValueError for a negative bit duration.

4.1.1.8 test_negative_sample_rate()

```
BPSK_modulation_test.TestBPSKModulation.test_negative_sample_rate (
              self )
```

Test the function with a negative sample rate.

Verifies:
- The function raises a ValueError for a negative sample rate.

4.1.1.9 test_single_bit()

```
BPSK_modulation_test.TestBPSKModulation.test_single_bit (
              self )

Test the BPSK modulation function with a single-bit binary data input.

Verifies:
- The generated signals correspond to the single bit.
```

4.1.1.10 test_zero_bit_duration()

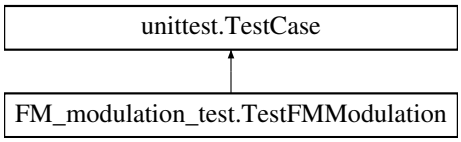
```
BPSK_modulation_test.TestBPSKModulation.test_zero_bit_duration (
              self )

Test the BPSK modulation function with zero bit duration.

Verifies:
- The function returns empty arrays.
```

The documentation for this class was generated from the following file:

- PSK-BPSK+tests/BPSK_modulation_test.py

4.2 FM_modulation_test.TestFMModulation Class Reference

Inheritance diagram for FM_modulation_test.TestFMModulation:



Public Member Functions

- test_increasing_carrier_frequency (self)
- test_frequency_deviation_change (self)
- test_short_signal_duration (self)
- test_low_sample_rate (self)
- test_high_sample_rate (self)
- test_signal_amplitude_variation (self)
- test_large_duration (self)
- test_different_message_frequencies (self)
- test_invalid_input (self)
- test_negative_frequency_deviation (self)

4.2.1 Member Function Documentation

4.2.1.1 test_different_message_frequencies()

```
FM_modulation_test.TestFMModulation.test_different_message_frequencies (
              self )

Test FM modulation with different frequencies in the message signal.

Verifies:
- The FM signal reflects the changing message signal frequency.
```

4.2.1.2 test_frequency_deviation_change()

```
FM_modulation_test.TestFMModulation.test_frequency_deviation_change (
              self )
```

Test FM modulation with varying frequency deviation.

Verifies:
- The maximum instantaneous frequency deviation matches or exceeds the set value.

4.2.1.3 test_high_sample_rate()

```
FM_modulation_test.TestFMModulation.test_high_sample_rate (
              self )
```

Test FM modulation with a very high sampling rate.

Verifies:
- The function handles high-resolution signals correctly.

4.2.1.4 test_increasing_carrier_frequency()

```
FM_modulation_test.TestFMModulation.test_increasing_carrier_frequency (
              self )
```

Test FM modulation with a standard carrier frequency and parameters.

Verifies:
- Signal lengths are consistent across all generated components.

4.2.1.5 test_invalid_input()

```
FM_modulation_test.TestFMModulation.test_invalid_input (
              self )
```

Test FM modulation with invalid inputs.

Verifies:
- The function raises a ValueError for invalid parameter combinations.

4.2.1.6 test_large_duration()

```
FM_modulation_test.TestFMModulation.test_large_duration (
              self )
```

Test FM modulation with a very large signal duration.

Verifies:
- The function handles long signals without errors.

4.2.1.7 test_low_sample_rate()

```
FM_modulation_test.TestFMModulation.test_low_sample_rate (
              self )
```

Test FM modulation with a lower sampling rate.

Verifies:
- Signal lengths are consistent despite the lower resolution.

4.2.1.8 test_negative_frequency_deviation()

```
FM_modulation_test.TestFMModulation.test_negative_frequency_deviation (
              self )

Test FM modulation with a negative frequency deviation.

Verifies:
- The function raises a ValueError.
```

4.2.1.9 test_short_signal_duration()

```
FM_modulation_test.TestFMModulation.test_short_signal_duration (
              self )

Test FM modulation with a shorter signal duration.

Verifies:
- The total duration of the generated signal is as expected.
```

4.2.1.10 test_signal_amplitude_variation()

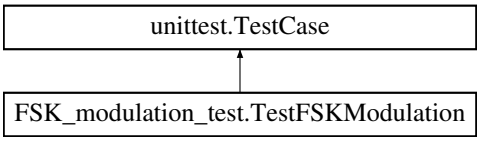
```
FM_modulation_test.TestFMModulation.test_signal_amplitude_variation (
              self )

Test FM modulation when the message signal amplitude changes.

Verifies:
- The FM signal adapts correctly to varying amplitudes.
```

The documentation for this class was generated from the following file:

- FM-FSK+tests/FM_modulation_test.py

4.3 FSK_modulation_test.TestFSKModulation Class Reference

Inheritance diagram for FSK_modulation_test.TestFSKModulation:



Public Member Functions

- test_basic_case (self)
- test_bit_duration (self)
- test_high_frequencies (self)
- test_large_binary_data (self)
- test_single_bit (self)
- test_invalid_binary_data (self)
- test_zero_bit_duration (self)
- test_negative_sample_rate (self)
- test_zero_carrier_frequencies (self)
- test_empty_binary_data (self)

4.3.1 Member Function Documentation

4.3.1.1 test_basic_case()

```
FSK_modulation_test.TestFSKModulation.test_basic_case (
              self )
```

Test the basic functionality of the FSK modulation function.

Verifies:
- The lengths of all generated signals are consistent.
- The modulating signal corresponds correctly to the binary data input.

4.3.1.2 test_bit_duration()

```
FSK_modulation_test.TestFSKModulation.test_bit_duration (
              self )
```

Test the function with varying bit durations.

Verifies:
- The total duration of the generated signal matches the expected value.

4.3.1.3 test_empty_binary_data()

```
FSK_modulation_test.TestFSKModulation.test_empty_binary_data (
              self )
```

Test the function with empty binary data.

Verifies:
- The function returns empty arrays when the binary data is empty.

4.3.1.4 test_high_frequencies()

```
FSK_modulation_test.TestFSKModulation.test_high_frequencies (
              self )
```

Test the function with high carrier frequencies.

Verifies:
- The carrier signals are normalized sine waves with amplitudes in the range [-1, 1].

4.3.1.5 test_invalid_binary_data()

```
FSK_modulation_test.TestFSKModulation.test_invalid_binary_data (
              self )
```

Test the function with invalid binary input data.

Verifies:
- The function raises a ValueError for non-binary input data.

4.3.1.6 test_large_binary_data()

```
FSK_modulation_test.TestFSKModulation.test_large_binary_data (
              self )
```

Test the FSK modulation function with a large binary data input.

Verifies:
- The function scales appropriately without errors.

4.3.1.7 test_negative_sample_rate()

```
FSK_modulation_test.TestFSKModulation.test_negative_sample_rate (
              self )

Test the function with a negative sample rate.

Verifies:
- The function raises a ValueError for a negative sample rate.
```

4.3.1.8 test_single_bit()

```
FSK_modulation_test.TestFSKModulation.test_single_bit (
              self )

Test the FSK modulation function with a single-bit binary data input.

Verifies:
- The generated signals correspond to the single bit.
```

4.3.1.9 test_zero_bit_duration()

```
FSK_modulation_test.TestFSKModulation.test_zero_bit_duration (
              self )

Test the FSK modulation function with zero bit duration.

Verifies:
- The function returns empty arrays.
```

4.3.1.10 test_zero_carrier_frequencies()

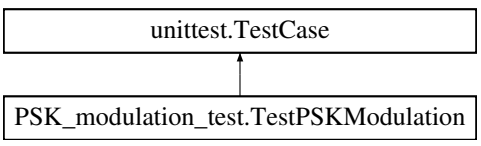
```
FSK_modulation_test.TestFSKModulation.test_zero_carrier_frequencies (
              self )

Test the function with zero carrier frequencies.

Verifies:
- The function does not raise an error, but the output signals are all zeros.
```

The documentation for this class was generated from the following file:

- FM-FSK+tests/FSK_modulation_test.py

4.4 PSK_modulation_test.TestPSKModulation Class Reference

Inheritance diagram for PSK_modulation_test.TestPSKModulation:



Public Member Functions

- test_basic_case (self)
- test_bit_duration (self)
- test_high_frequency (self)
- test_large_binary_data (self)

- test_single_bit (self)
- test_invalid_binary_data (self)
- test_zero_bit_duration (self)
- test_negative_sample_rate (self)
- test_negative_bit_duration (self)
- test_empty_binary_data (self)

4.4.1 Member Function Documentation

4.4.1.1 test_basic_case()

```
PSK_modulation_test.TestPSKModulation.test_basic_case (
              self )
```

Test the basic functionality of the PSK modulation function.

Verifies:
- The lengths of all generated signals are consistent.
- The modulating signal corresponds correctly to the binary data input.

4.4.1.2 test_bit_duration()

```
PSK_modulation_test.TestPSKModulation.test_bit_duration (
              self )
```

Test the function with varying bit durations.

Verifies:
- The total duration of the generated signal matches the expected value.

4.4.1.3 test_empty_binary_data()

```
PSK_modulation_test.TestPSKModulation.test_empty_binary_data (
              self )
```

Test the function with empty binary data.

Verifies:
- The function returns empty arrays when the binary data is empty.

4.4.1.4 test_high_frequency()

```
PSK_modulation_test.TestPSKModulation.test_high_frequency (
              self )
```

Test the function with a high carrier frequency.

Verifies:
- The carrier signal is a normalized sine wave with amplitude in the range [-1, 1].

4.4.1.5 test_invalid_binary_data()

```
PSK_modulation_test.TestPSKModulation.test_invalid_binary_data (
              self )
```

Test the function with invalid binary input data.

Verifies:
- The function raises a ValueError for non-binary input data.

4.4.1.6 test_large_binary_data()

```
PSK_modulation_test.TestPSKModulation.test_large_binary_data (
              self )
```

Test the PSK modulation function with a large binary data input.

Verifies:
- The function scales appropriately without errors.

4.4.1.7 test_negative_bit_duration()

```
PSK_modulation_test.TestPSKModulation.test_negative_bit_duration (
              self )
```

Test the function with a negative bit duration.

Verifies:
- The function raises a ValueError for a negative bit duration.

4.4.1.8 test_negative_sample_rate()

```
PSK_modulation_test.TestPSKModulation.test_negative_sample_rate (
              self )
```

Test the function with a negative sample rate.

Verifies:
- The function raises a ValueError for a negative sample rate.

4.4.1.9 test_single_bit()

```
PSK_modulation_test.TestPSKModulation.test_single_bit (
              self )
```

Test the PSK modulation function with a single-bit binary data input.

Verifies:
- The generated signals correspond to the single bit.

4.4.1.10 test_zero_bit_duration()

```
PSK_modulation_test.TestPSKModulation.test_zero_bit_duration (
              self )
```

Test the PSK modulation function with zero bit duration.

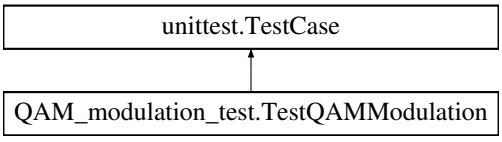
Verifies:
- The function returns empty arrays.

The documentation for this class was generated from the following file:

- PSK-BPSK+tests/PSK_modulation_test.py

4.5 QAM_modulation_test.TestQAMModulation Class Reference

Inheritance diagram for QAM_modulation_test.TestQAMModulation:



Public Member Functions

- test_basic_case (self)
- test_bit_duration (self)
- test_high_frequency (self)
- test_large_binary_data (self)
- test_single_symbol (self)
- test_invalid_binary_data_length (self)
- test_invalid_constellation_points (self)
- test_invalid_constellation_points_number (self)
- test_negative_sample_rate (self)
- test_empty_binary_data (self)

4.5.1 Member Function Documentation

4.5.1.1 test_basic_case()

```
QAM_modulation_test.TestQAMModulation.test_basic_case (
              self )
```

Test the basic functionality of the QAM modulation function.

Verifies:
- The lengths of all generated signals are consistent.
- The modulating signal has the correct length.

4.5.1.2 test_bit_duration()

```
QAM_modulation_test.TestQAMModulation.test_bit_duration (
              self )
```

Test the function with varying bit durations.

Verifies:
- The total duration of the generated signal matches the expected value.

4.5.1.3 test_empty_binary_data()

```
QAM_modulation_test.TestQAMModulation.test_empty_binary_data (
              self )
```

Test the function with empty binary data.

Verifies:
- The function returns empty arrays when the binary data is empty.

4.5.1.4 test_high_frequency()

```
QAM_modulation_test.TestQAMModulation.test_high_frequency (
              self )
```

Test the function with a high carrier frequency.

Verifies:
- The carrier signals are normalized sine and cosine waves with amplitude in the range [-1, 1].

4.5.1.5 test_invalid_binary_data_length()

```
QAM_modulation_test.TestQAMModulation.test_invalid_binary_data_length (
              self )
```

Test the function with invalid binary input data length.

Verifies:
- The function raises a ValueError for binary data length not a multiple of bits per symbol.

4.5.1.6 test_invalid_constellation_points()

```
QAM_modulation_test.TestQAMModulation.test_invalid_constellation_points (
              self )
```

Test the function with invalid constellation points.

Verifies:
- The function raises a ValueError for non-complex constellation points.

4.5.1.7 test_invalid_constellation_points_number()

```
QAM_modulation_test.TestQAMModulation.test_invalid_constellation_points_number (
              self )
```

Test the function with invalid number of constellation points.

Verifies:
- The function raises a ValueError for number of constellation points not a power of 2.

4.5.1.8 test_large_binary_data()

```
QAM_modulation_test.TestQAMModulation.test_large_binary_data (
              self )
```

Test the QAM modulation function with a large binary data input.

Verifies:
- The function scales appropriately without errors.

4.5.1.9 test_negative_sample_rate()

```
QAM_modulation_test.TestQAMModulation.test_negative_sample_rate (
              self )
```

Test the QAM modulation function with a negative sample rate.

Verifies:
- The function raises a ValueError when sample_rate is negative.

4.5.1.10 test_single_symbol()

```
QAM_modulation_test.TestQAMModulation.test_single_symbol (
              self )
```

Test the QAM modulation function with a single symbol binary data input.

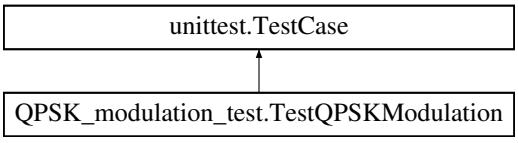
Verifies:
- The generated signals correspond to the single symbol.

The documentation for this class was generated from the following file:

- QAM-QPSK+tests/QAM_modulation_test.py

4.6 QPSK_modulation_test.TestQPSKModulation Class Reference

Inheritance diagram for QPSK_modulation_test.TestQPSKModulation:



Public Member Functions

- test_basic_case (self)
- test_bit_duration (self)
- test_high_frequency (self)
- test_large_binary_data (self)
- test_single_symbol (self)
- test_invalid_binary_data_length (self)
- test_negative_sample_rate (self)
- test_empty_binary_data (self)
- test_zero_carrier_frequency (self)
- test_uneven_sample_rate_bit_duration (self)

4.6.1 Member Function Documentation

4.6.1.1 test_basic_case()

```
QPSK_modulation_test.TestQPSKModulation.test_basic_case (
              self )
```

Test the basic functionality of the QPSK modulation function.

Verifies:
- The lengths of all generated signals are consistent.
- The modulating signal has the correct length.

4.6.1.2 test_bit_duration()

```
QPSK_modulation_test.TestQPSKModulation.test_bit_duration (
              self )
```

Test the function with varying bit durations.

Verifies:
- The total duration of the generated signal matches the expected value.

4.6.1.3 test_empty_binary_data()

```
QPSK_modulation_test.TestQPSKModulation.test_empty_binary_data (
              self )
```

Test the function with empty binary data.

Verifies:
- The function returns empty arrays when the binary data is empty.

4.6.1.4 test_high_frequency()

```
QPSK_modulation_test.TestQPSKModulation.test_high_frequency (
              self )
```

Test the function with a high carrier frequency.

Verifies:
- The carrier signals are normalized sine and cosine waves with amplitude in the range [-1, 1].

4.6.1.5 test_invalid_binary_data_length()

```
QPSK_modulation_test.TestQPSKModulation.test_invalid_binary_data_length (
              self )
```

Test the function with invalid binary input data length.

Verifies:
- The function raises a ValueError for binary data length not a multiple of 2.

4.6.1.6 test_large_binary_data()

```
QPSK_modulation_test.TestQPSKModulation.test_large_binary_data (
              self )

Test the QPSK modulation function with a large binary data input.

Verifies:
- The function scales appropriately without errors.
```

4.6.1.7 test_negative_sample_rate()

```
QPSK_modulation_test.TestQPSKModulation.test_negative_sample_rate (
              self )

Test the QPSK modulation function with a negative sample rate.

Verifies:
- The function raises a ValueError when sample_rate is negative.
```

4.6.1.8 test_single_symbol()

```
QPSK_modulation_test.TestQPSKModulation.test_single_symbol (
              self )

Test the QPSK modulation function with a single symbol binary data input.

Verifies:
- The generated signals correspond to the single symbol.
```

4.6.1.9 test_uneven_sample_rate_bit_duration()

```
QPSK_modulation_test.TestQPSKModulation.test_uneven_sample_rate_bit_duration (
              self )

Test the function with a sample rate that is not a multiple of the bit duration.

Verifies:
- The function still generates signals without errors.
```

4.6.1.10 test_zero_carrier_frequency()

```
QPSK_modulation_test.TestQPSKModulation.test_zero_carrier_frequency (
              self )

Test the function with a zero carrier frequency.

Verifies:
- The carrier signals are constant (all zeros).
```

The documentation for this class was generated from the following file:

- QAM-QPSK+tests/QPSK_modulation_test.py

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