Spin Echo

1. a)

In [131…

```
import sys
# !conda install --yes --prefix {sys.prefix} numpy
# !conda install --yes --prefix {sys.prefix} qiskit
# !conda install --yes --prefix {sys.prefix} matplotlib
# !{sys.executable} -m pip install pyppeteer
```

```
Collecting pyppeteer
  Downloading pyppeteer-0.2.6-py3-none-any.whl (83 kB)
     |████████████████████████████████| 83 kB 2.6 MB/s eta 0:00:011
Collecting appdirs<2.0.0,>=1.4.3
  Using cached appdirs-1.4.4-py2.py3-none-any.whl (9.6 kB)
Requirement already satisfied: importlib-metadata>=1.4 in /Users/adamcarriker/opt/anaconda
3/envs/env_qiskit/lib/python3.9/site-packages (from pyppeteer) (4.8.1)
Collecting pyee<9.0.0,>=8.1.0
  Downloading pyee-8.2.2-py2.py3-none-any.whl (12 kB)
Requirement already satisfied: urllib3<2.0.0,>=1.25.8 in /Users/adamcarriker/opt/anaconda
3/envs/env_qiskit/lib/python3.9/site-packages (from pyppeteer) (1.26.5)
Requirement already satisfied: websockets<10.0,>=9.1 in /Users/adamcarriker/opt/anaconda3/
envs/env_qiskit/lib/python3.9/site-packages (from pyppeteer) (9.1)
Collecting tqdm<5.0.0,>=4.42.1
  Downloading tqdm-4.62.3-py2.py3-none-any.whl (76 kB)
     |████████████████████████████████| 76 kB 10.1 MB/s eta 0:00:01
Requirement already satisfied: zipp>=0.5 in /Users/adamcarriker/opt/anaconda3/envs/env_qis
kit/lib/python3.9/site-packages (from importlib-metadata>=1.4->pyppeteer) (3.6.0)
Installing collected packages: tqdm, pyee, appdirs, pyppeteer
Successfully installed appdirs-1.4.4 pyee-8.2.2 pyppeteer-0.2.6 tqdm-4.62.3
```

In [110…

```
import numpy as np
from qiskit import *
from matplotlib import pyplot
from math import pi
```

In [ ]:

```
thetas = [i*pi/10 for i in range(0,11)]
shots = 100
```

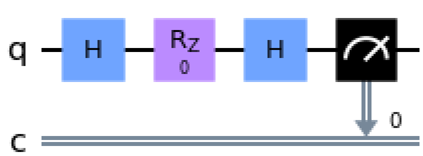
In [122…

```
import matplotlib.pyplot as plt
import numpy as np

def plot_results(counts_arr):

    zeros_count = [count[0] for count in counts_arr] #+ [sum([count[0] for count in counts
    ones_count = [count[1] for count in counts_arr] #+ [sum([count[1] for count in counts_
    ones_pct = [count/shots for count in ones_count]

    fig, ax = plt.subplots()
    labels = [f'{i}/10*pi' for i in range(len(thetas))] #+ ['Average']
    x = np.arange(len(labels))
    width=0.35

#     c1 = ax.bar(x - width/2, zeros_count, width, label='Output = 0')
    c2 = ax.bar(x + width/2, ones_pct, width, label='Output = 1')

    ax.set_ylabel('Output 1 Average')
    ax.set_xlabel('Theta')
```

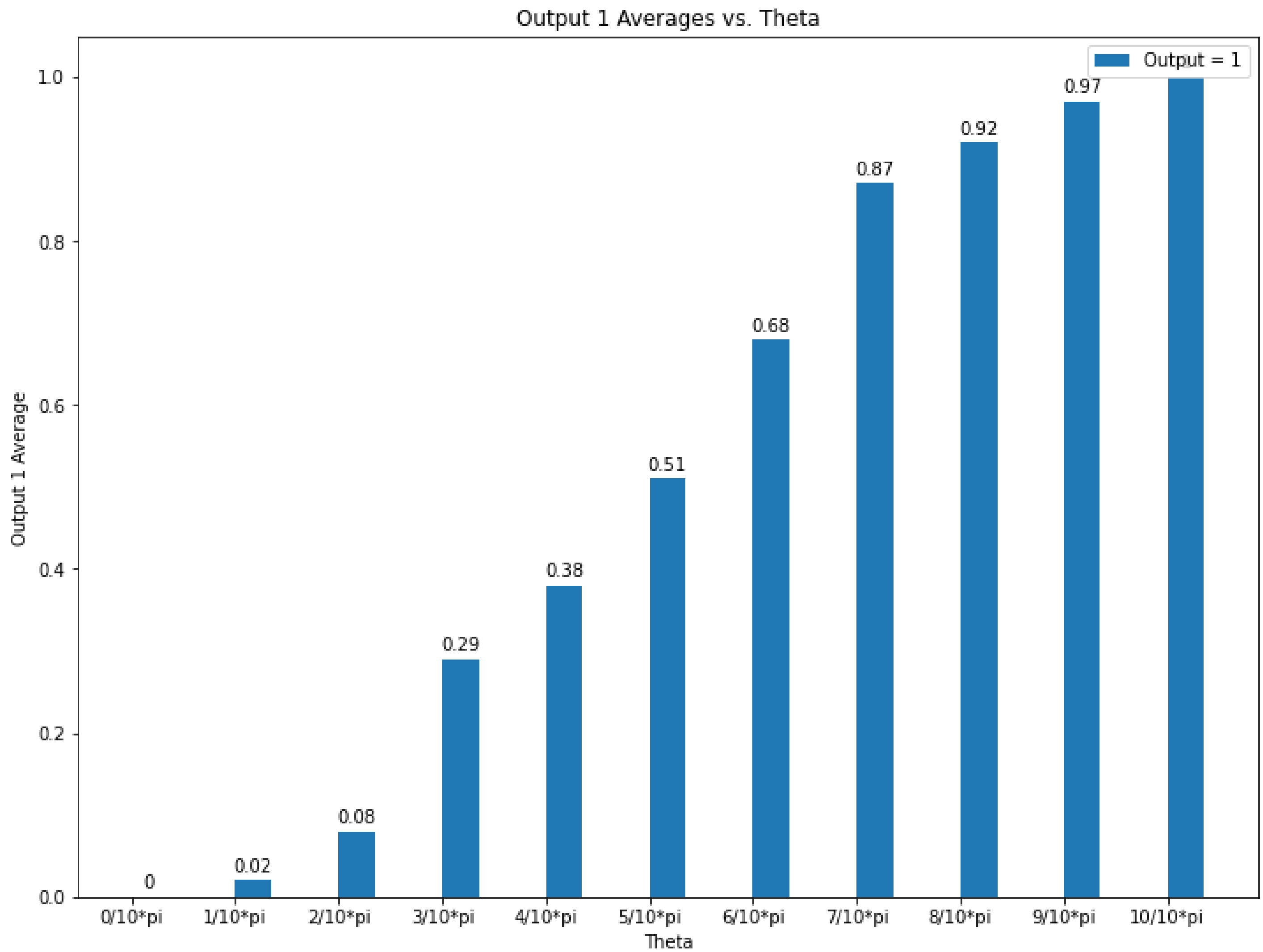
```
    ax.set_title('Output 1 Averages vs. Theta')
    ax.set_xticks(x)
    ax.set_xticklabels(labels)
    ax.legend()

#     ax.bar_label(c1, padding=3)
    ax.bar_label(c2, padding=3)

    fig.set_size_inches(12, 9)

    plt.show()
```

In [123…

```
counts_arr = [ [] for i in range(len(thetas)) ]

for i, theta in enumerate(thetas):

    # Build circuit
    qc = QuantumCircuit(1,1)
    qc.h(0)
    qc.rz(theta,0)
    qc.h(0)
    qc.measure(0,0)
    if i==0:
        qc.draw('mpl')
        pyplot.show()

    # Simulate circuit using Aer's qasm_simulator
    backend_sim = Aer.get_backend('qasm_simulator')
    job_sim = backend_sim.run(transpile(qc, backend_sim), shots=shots)
    result_sim = job_sim.result()
    counts = result_sim.get_counts(qc)

    # collect counts of simulation output
    counts_arr[i].append( counts['0'] if '0' in counts else 0 )
    counts_arr[i].append( counts['1'] if '1' in counts else 0 )

    print(f'theta={i}/10*pi\tcounts: {counts}\tavg: {counts_arr[i][1]/shots*100:.1f}%')

plot_results(counts_arr)
```




```
theta=0/10*pi   counts: {'0': 100}      avg: 0.0%
theta=1/10*pi   counts: {'1': 2, '0': 98}       avg: 2.0%
theta=2/10*pi   counts: {'1': 8, '0': 92}       avg: 8.0%
theta=3/10*pi   counts: {'0': 71, '1': 29}      avg: 29.0%
theta=4/10*pi   counts: {'0': 62, '1': 38}      avg: 38.0%
theta=5/10*pi   counts: {'0': 49, '1': 51}      avg: 51.0%
theta=6/10*pi   counts: {'1': 68, '0': 32}      avg: 68.0%
theta=7/10*pi   counts: {'0': 13, '1': 87}      avg: 87.0%
theta=8/10*pi   counts: {'0': 8, '1': 92}       avg: 92.0%
theta=9/10*pi   counts: {'0': 3, '1': 97}       avg: 97.0%
theta=10/10*pi  counts: {'1': 100}      avg: 100.0%
```

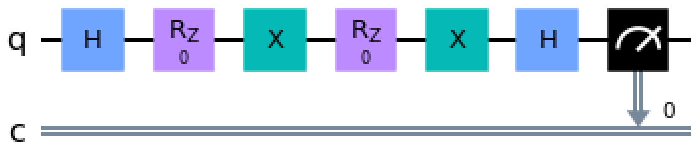


1. b)

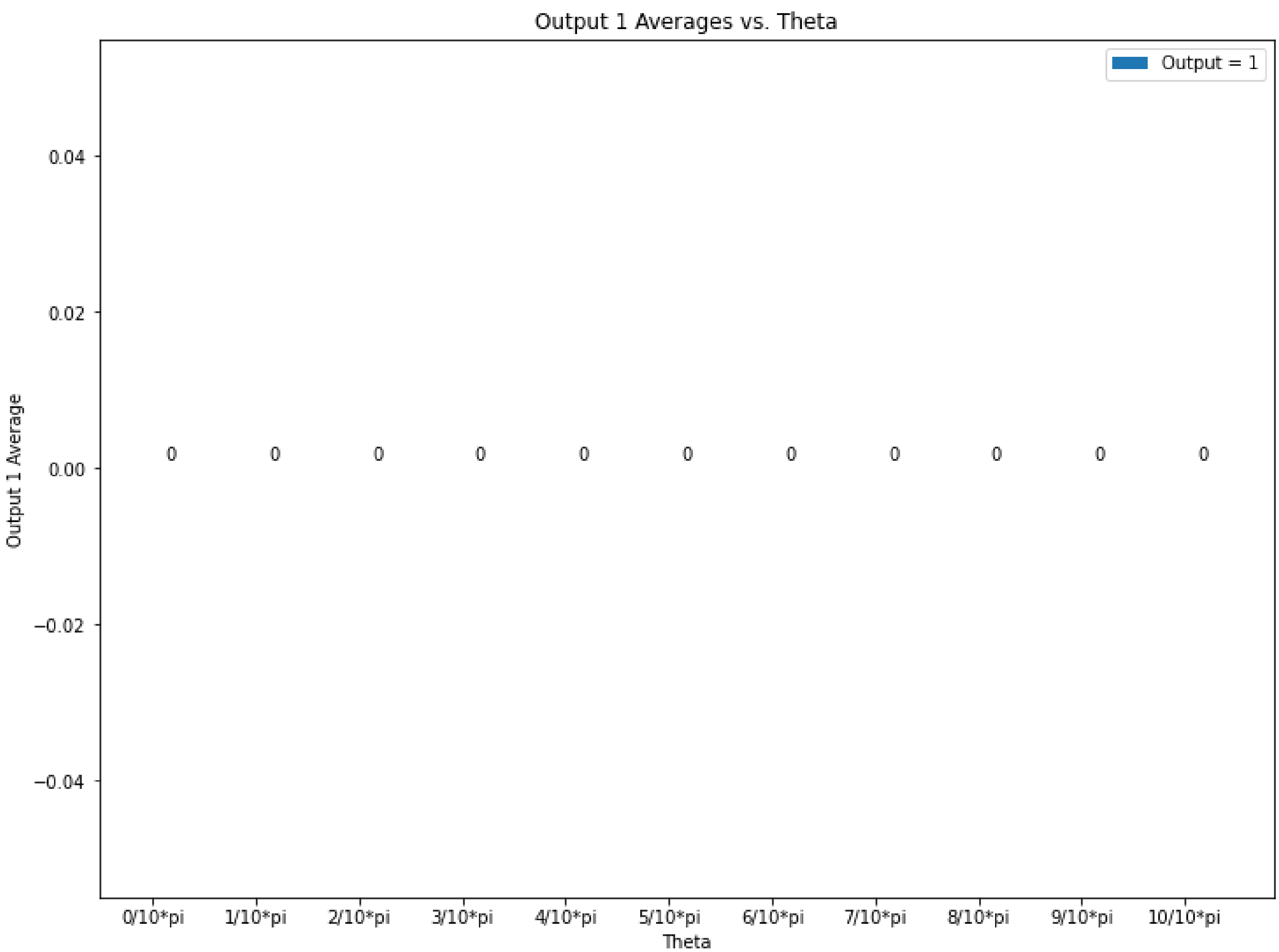
In [124…

```
counts_arr = [ [] for i in range(len(thetas)) ]
for i, theta in enumerate(thetas):

    # Build circuit
    qc = QuantumCircuit(1,1)
    qc.h(0)
    qc.rz(theta/2,0)
    qc.x(0)
    qc.rz(theta/2,0)
    qc.x(0)
    qc.h(0)
    qc.measure(0,0)
    if i==0:
        qc.draw('mpl')
        pyplot.show()

    # Simulate circuit using Aer's qasm_simulator
    backend_sim = Aer.get_backend('qasm_simulator')
    job_sim = backend_sim.run(transpile(qc, backend_sim), shots=shots)
    result_sim = job_sim.result()
    counts = result_sim.get_counts(qc)

    # collect counts of simulation output
    counts_arr[i].append( counts['0'] if '0' in counts else 0 )
    counts_arr[i].append( counts['1'] if '1' in counts else 0 )

    print(f'theta={i}/10*pi\tcounts: {counts}\tavg: {counts_arr[i][1]/shots:.2f}%')
```

```
plot_results(counts_arr)
```




```
theta=0/10*pi   counts: {'0': 100}      avg: 0.00%
theta=1/10*pi   counts: {'0': 100}      avg: 0.00%
theta=2/10*pi   counts: {'0': 100}      avg: 0.00%
theta=3/10*pi   counts: {'0': 100}      avg: 0.00%
theta=4/10*pi   counts: {'0': 100}      avg: 0.00%
theta=5/10*pi   counts: {'0': 100}      avg: 0.00%
theta=6/10*pi   counts: {'0': 100}      avg: 0.00%
theta=7/10*pi   counts: {'0': 100}      avg: 0.00%
theta=8/10*pi   counts: {'0': 100}      avg: 0.00%
theta=9/10*pi   counts: {'0': 100}      avg: 0.00%
theta=10/10*pi  counts: {'0': 100}      avg: 0.00%
```



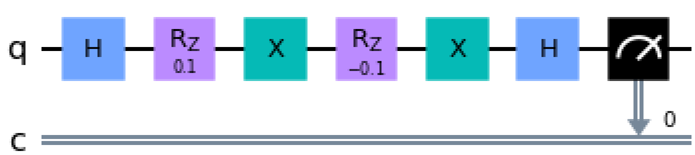
1. c)

In [125…

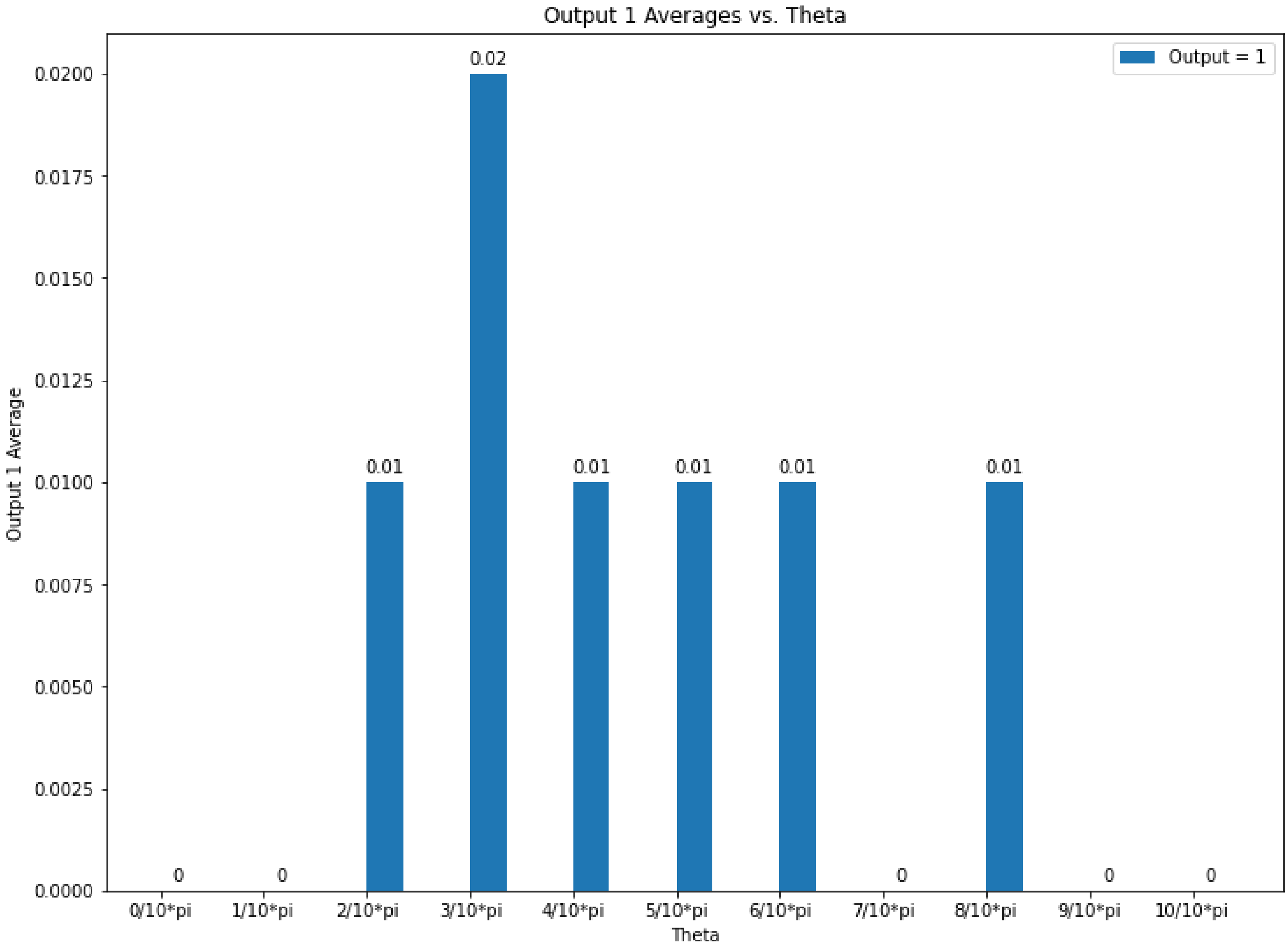
```
deltas = [0.1, 0.2]

for delta in deltas:
    counts_arr = [ [] for i in range(len(thetas)) ]
    print(f"\n-----\nDelta: {delta}")
```

```python
    for i, theta in enumerate(thetas):

        # Build circuit
        qc = QuantumCircuit(1,1)
        qc.h(0)
        qc.rz(theta/2+delta,0)
        qc.x(0)
        qc.rz(theta/2-delta,0)
        qc.x(0)
        qc.h(0)
        qc.measure(0,0)
        if i==0:
            qc.draw('mpl')
            pyplot.show()

        # Simulate circuit using Aer's qasm_simulator
        backend_sim = Aer.get_backend('qasm_simulator')
        job_sim = backend_sim.run(transpile(qc, backend_sim), shots=shots)
        result_sim = job_sim.result()
        counts = result_sim.get_counts(qc)

        # collect counts of simulation output
        counts_arr[i].append( counts['0'] if '0' in counts else 0 )
        counts_arr[i].append( counts['1'] if '1' in counts else 0 )

        print(f'theta={i}/10*pi\tcounts: {counts}\tavg: {counts_arr[i][1]/shots:.2f}%')

    plot_results(counts_arr)
```

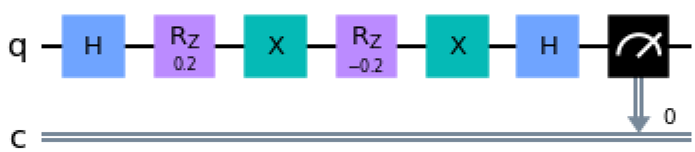
```
-----
Delta: 0.1
```



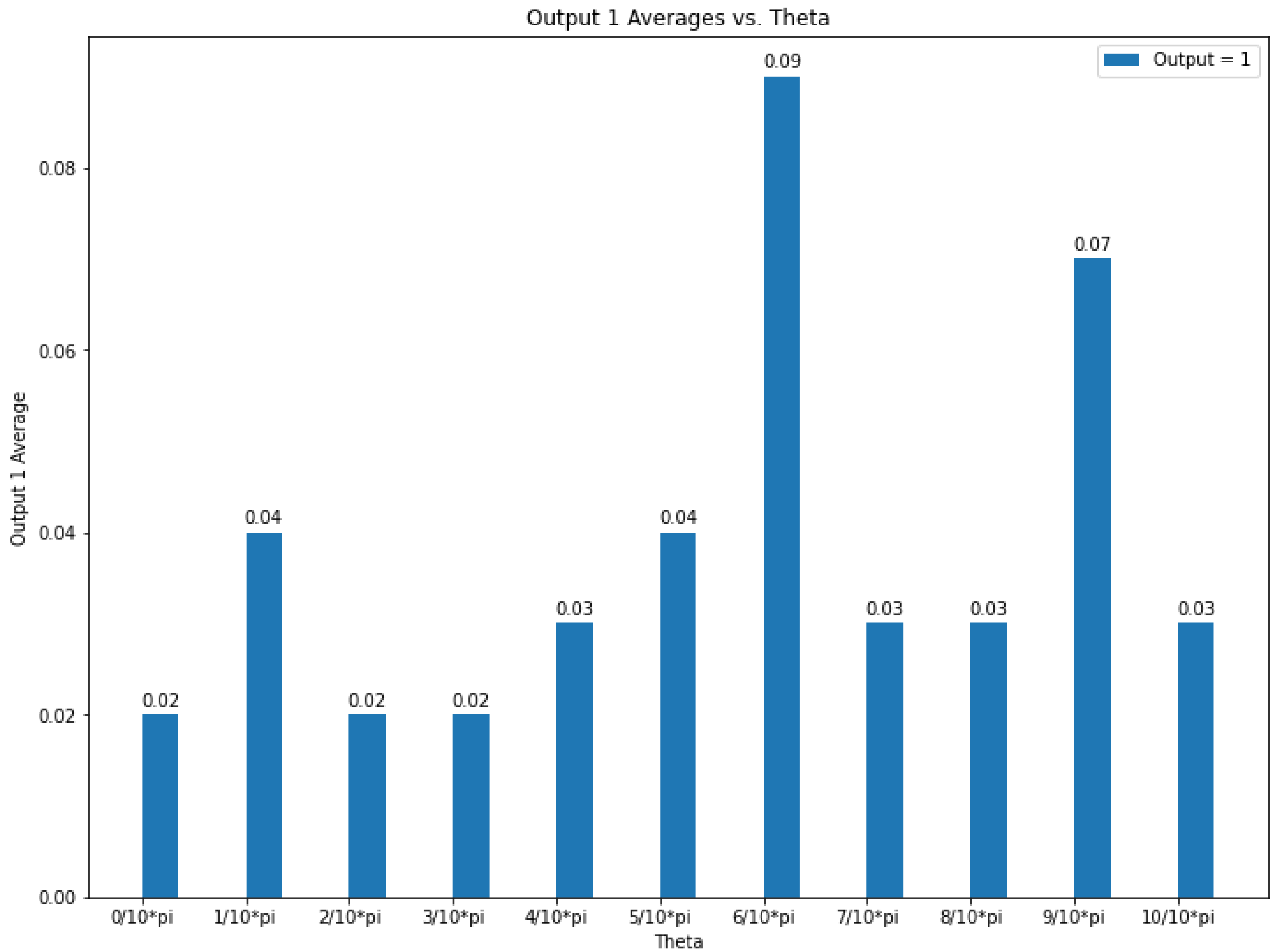

```
theta=0/10*pi   counts: {'0': 100}      avg: 0.00%
theta=1/10*pi   counts: {'0': 100}      avg: 0.00%
theta=2/10*pi   counts: {'1': 1, '0': 99}       avg: 0.01%
theta=3/10*pi   counts: {'1': 2, '0': 98}       avg: 0.02%
theta=4/10*pi   counts: {'1': 1, '0': 99}       avg: 0.01%
theta=5/10*pi   counts: {'1': 1, '0': 99}       avg: 0.01%
theta=6/10*pi   counts: {'1': 1, '0': 99}       avg: 0.01%
theta=7/10*pi   counts: {'0': 100}      avg: 0.00%
theta=8/10*pi   counts: {'1': 1, '0': 99}       avg: 0.01%
theta=9/10*pi   counts: {'0': 100}      avg: 0.00%
theta=10/10*pi  counts: {'0': 100}      avg: 0.00%
```




```
-----
Delta: 0.2
```




```
theta=0/10*pi    counts: {'1': 2, '0': 98}       avg: 0.02%
theta=1/10*pi    counts: {'1': 4, '0': 96}       avg: 0.04%
theta=2/10*pi    counts: {'1': 2, '0': 98}       avg: 0.02%
theta=3/10*pi    counts: {'1': 2, '0': 98}       avg: 0.02%
theta=4/10*pi    counts: {'1': 3, '0': 97}       avg: 0.03%
theta=5/10*pi    counts: {'1': 4, '0': 96}       avg: 0.04%
theta=6/10*pi    counts: {'1': 9, '0': 91}       avg: 0.09%
theta=7/10*pi    counts: {'1': 3, '0': 97}       avg: 0.03%
theta=8/10*pi    counts: {'1': 3, '0': 97}       avg: 0.03%
theta=9/10*pi    counts: {'1': 7, '0': 93}       avg: 0.07%
theta=10/10*pi   counts: {'1': 3, '0': 97}       avg: 0.03%
```



1.d)

The output of the circuit in part a starts off as entirely 0 as theta=0, and as theta increases it starts becoming a mixture of 0 and 1. Once theta passes 1/2 * pi, the output value 1 starts becoming the more likely output up until theata=pi, at which point the output is 1 with certainty.

The circuit outputs in parts b and c don't seem to change as theta changes, with the circuit in part b having output value 0 with certainty for all values of theta. However, the circuit in part c, with delta=0.1, is measured with value 0 as well as 1 (with a small probability ~ 1%), and this increases to an output value 1 with probability ~4% as delta increases to 0.2. This indicates that the symetry of the circuit in part b which allows the state |0> to stay unchanged through the circuit is slightly marred by the addition then subtraction of the delta value from the two RZ gates, respectivley.

2.a)

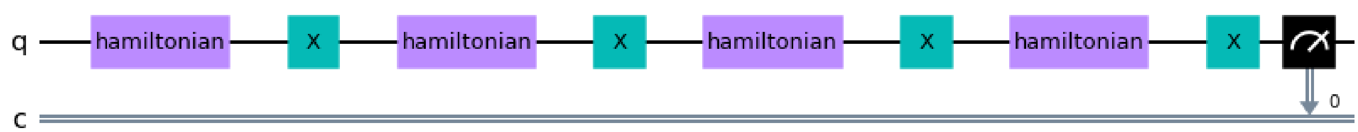
In [126…

```
from qiskit.quantum_info import Operator
from qiskit.extensions import HamiltonianGate
from qiskit.opflow import I, X, Y, Z
```

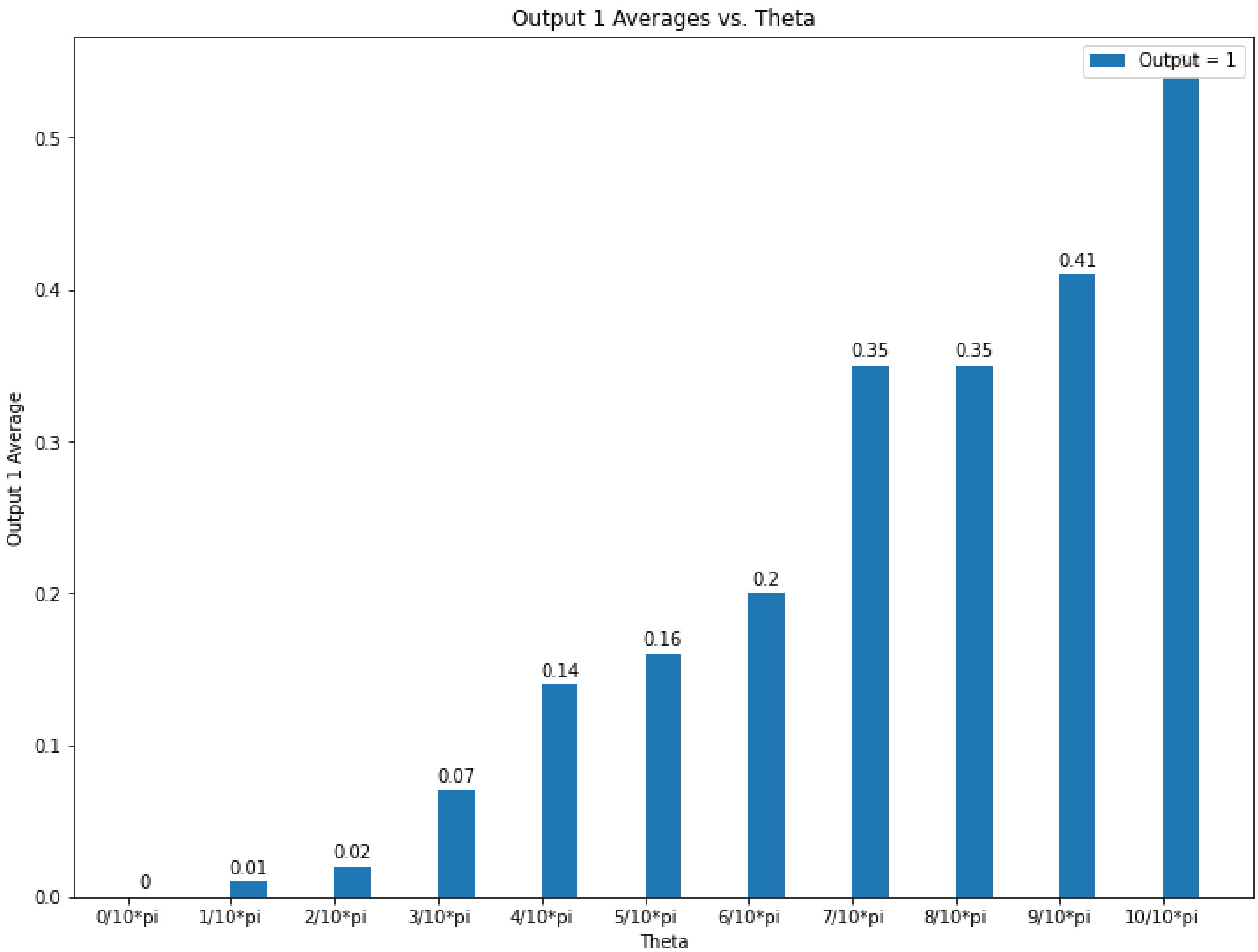
In [127…

```
counts_arr = [ [] for i in range(len(thetas)) ]
for i, theta in enumerate(thetas):

    # Define operator in exponent
```

```
    op = X + Y + Z

    # Define coefficient in exponent
    c = (theta/4)/2*((1/3)**(1/2))

    # Create HamiltonianGate, which is defined as exp(-i*op*c)
    V_gate = HamiltonianGate(op, c)

    # Define circuit
    qc = QuantumCircuit(1,1)
    qc.append(V_gate, [0])
    qc.x(0)
    qc.append(V_gate, [0])
    qc.x(0)
    qc.append(V_gate, [0])
    qc.x(0)
    qc.append(V_gate, [0])
    qc.x(0)
    qc.measure(0,0)

    # Draw circuit once
    if i==0:
        qc.draw('mpl')
        pyplot.show()

    # Simulate circuit using Aer's qasm_simulator
    backend_sim = Aer.get_backend('qasm_simulator')
    job_sim = backend_sim.run(transpile(qc, backend_sim), shots=shots)
    result_sim = job_sim.result()
    counts = result_sim.get_counts(qc)

    # collect counts of simulation output
    counts_arr[i].append( counts['0'] if '0' in counts else 0 )
    counts_arr[i].append( counts['1'] if '1' in counts else 0 )

    print(f'theta={i}/10*pi\tcounts: {counts}\tavg: {counts_arr[i][1]/shots:.2f}%')

plot_results(counts_arr)
```



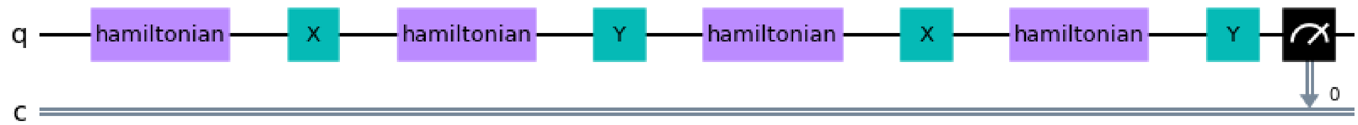

```
theta=0/10*pi   counts: {'0': 100}      avg: 0.00%
theta=1/10*pi   counts: {'1': 1, '0': 99}       avg: 0.01%
theta=2/10*pi   counts: {'1': 2, '0': 98}       avg: 0.02%
theta=3/10*pi   counts: {'1': 7, '0': 93}       avg: 0.07%
theta=4/10*pi   counts: {'1': 14, '0': 86}      avg: 0.14%
theta=5/10*pi   counts: {'0': 84, '1': 16}      avg: 0.16%
theta=6/10*pi   counts: {'1': 20, '0': 80}      avg: 0.20%
theta=7/10*pi   counts: {'1': 35, '0': 65}      avg: 0.35%
theta=8/10*pi   counts: {'1': 35, '0': 65}      avg: 0.35%
theta=9/10*pi   counts: {'1': 41, '0': 59}      avg: 0.41%
theta=10/10*pi  counts: {'1': 54, '0': 46}      avg: 0.54%
```



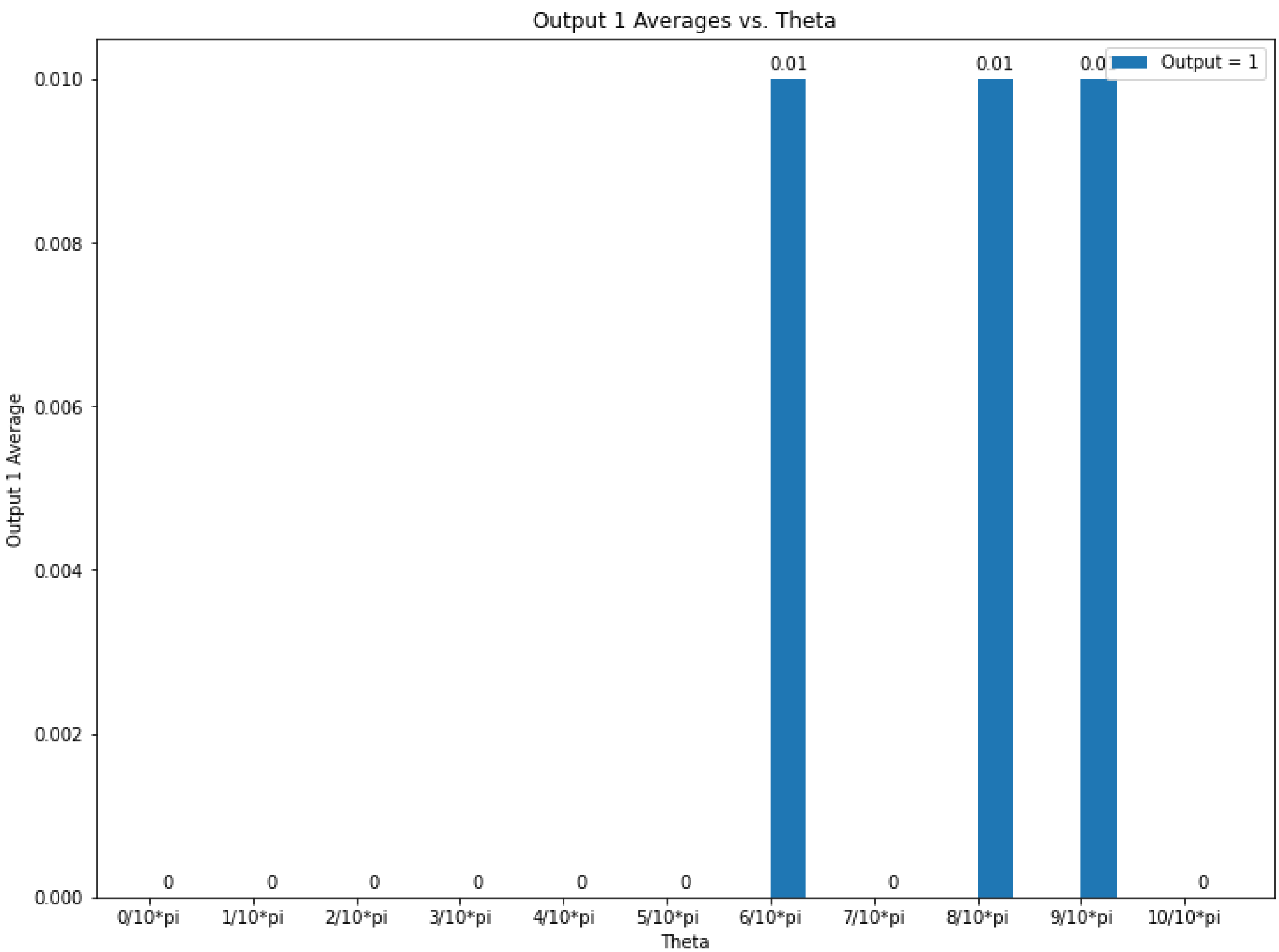
In [128…

```
counts_arr = [ [] for i in range(len(thetas)) ]
for i, theta in enumerate(thetas):

    # Define operator in exponent
    op = X + Y + Z

    # Define coefficient in exponent
    c = (theta/4)/2*((1/3)**(1/2))

    # Create HamiltonianGate, which is defined as exp(-i*op*c)
    V_gate = HamiltonianGate(op, c)

    # Define circuit
    qc = QuantumCircuit(1,1)
    qc.append(V_gate, [0])
    qc.x(0)
    qc.append(V_gate, [0])
    qc.y(0)
    qc.append(V_gate, [0])
    qc.x(0)
    qc.append(V_gate, [0])
    qc.y(0)
    qc.measure(0,0)

    # Draw circuit once
    if i==0:
        qc.draw('mpl')
        pyplot.show()

    # Simulate circuit using Aer's qasm_simulator
```

```
    backend_sim = Aer.get_backend('qasm_simulator')
    job_sim = backend_sim.run(transpile(qc, backend_sim), shots=shots)
    result_sim = job_sim.result()
    counts = result_sim.get_counts(qc)

    # collect counts of simulation output
    counts_arr[i].append( counts['0'] if '0' in counts else 0 )
    counts_arr[i].append( counts['1'] if '1' in counts else 0 )

    print(f'theta={i}/10*pi\tcounts: {counts}\tavg: {counts_arr[i][1]/shots:.2f}%')

plot_results(counts_arr)
```




```
theta=0/10*pi   counts: {'0': 100}      avg: 0.00%
theta=1/10*pi   counts: {'0': 100}      avg: 0.00%
theta=2/10*pi   counts: {'0': 100}      avg: 0.00%
theta=3/10*pi   counts: {'0': 100}      avg: 0.00%
theta=4/10*pi   counts: {'0': 100}      avg: 0.00%
theta=5/10*pi   counts: {'0': 100}      avg: 0.00%
theta=6/10*pi   counts: {'1': 1, '0': 99}       avg: 0.01%
theta=7/10*pi   counts: {'0': 100}      avg: 0.00%
theta=8/10*pi   counts: {'1': 1, '0': 99}       avg: 0.01%
theta=9/10*pi   counts: {'1': 1, '0': 99}       avg: 0.01%
theta=10/10*pi  counts: {'0': 100}      avg: 0.00%
```



The output of the circuit in part a changes drastically as theta goes from 0 -> pi. The output of the circuit in part b does not change very drastically as theta changes, mostly staying at 0 with certainty until theta reaches values close to pi. This indicates that the second circuit is more effective at reducing the decoherence of the qubit as the circuit progresses, and therefore is a better dynamic decoupling solution.