```
In [1]: import pulser
        import pulser_simulation
        import numpy as np
        import qutip
```

```
In [2]: pulser.AnalogDevice.to_abstract_repr()
```

Out[2]: '{"name": "AnalogDevice", "dimensions": 2, "rydberg_level": 60, "min_atom_distance": 5, "max_
        atom_num": 25, "max_radial_distance": 35, "interaction_coeff_xy": null, "supports_slm_mask":
        false, "max_layout_filling": 0.5, "max_sequence_duration": 4000, "max_runs": 2000, "reusable_
        channels": false, "pre_calibrated_layouts": [{"coordinates": [[-20.0, 0.0], [-17.5, -4.33012
        7], [-17.5, 4.330127], [-15.0, -8.660254], [-15.0, 0.0], [-15.0, 8.660254], [-12.5, -12.99038
        1], [-12.5, -4.330127], [-12.5, 4.330127], [-12.5, 12.990381], [-10.0, -17.320508], [-10.0,
        -8.660254], [-10.0, 0.0], [-10.0, 8.660254], [-10.0, 17.320508], [-7.5, -12.990381], [-7.5,
        -4.330127], [-7.5, 4.330127], [-7.5, 12.990381], [-5.0, -17.320508], [-5.0, -8.660254],
        [-5.0, 0.0], [-5.0, 8.660254], [-5.0, 17.320508], [-2.5, -12.990381], [-2.5, -4.330127],
        [-2.5, 4.330127], [-2.5, 12.990381], [0.0, -17.320508], [0.0, -8.660254], [0.0, 0.0], [0.0,
        8.660254], [0.0, 17.320508], [2.5, -12.990381], [2.5, -4.330127], [2.5, 4.330127], [2.5, 12.9
        90381], [5.0, -17.320508], [5.0, -8.660254], [5.0, 0.0], [5.0, 8.660254], [5.0, 17.320508],
        [7.5, -12.990381], [7.5, -4.330127], [7.5, 4.330127], [7.5, 12.990381], [10.0, -17.320508],
        [10.0, -8.660254], [10.0, 0.0], [10.0, 8.660254], [10.0, 17.320508], [12.5, -12.990381], [1
        2.5, -4.330127], [12.5, 4.330127], [12.5, 12.990381], [15.0, -8.660254], [15.0, 0.0], [15.0,
        8.660254], [17.5, -4.330127], [17.5, 4.330127], [20.0, 0.0]], "slug": "TriangularLatticeLayou
        t(61, 5.0\\u00b5m)"}], "accepts_new_layouts": false, "version": "1", "pulser_version": "1.2de
        v1", "channels": [{"id": "rydberg_global", "basis": "ground-rydberg", "addressing": "Global",
        "max_abs_detuning": 125.66370614359172, "max_amp": 12.566370614359172, "min_retarget_interval
        ": null, "fixed_retarget_t": null, "max_targets": null, "clock_period": 4, "min_duration": 16
        , "max_duration": 100000000, "mod_bandwidth": 8, "eom_config": {"limiting_beam": "RED", "max_
        limiting_amp": 188.49555921538757, "intermediate_detuning": 2827.4333882308138, "controlled_b
        eams": ["BLUE"], "mod_bandwidth": 40, "custom_buffer_time": 240}}], "is_virtual": false}'

```
In [3]: seq = pulser.Sequence(pulser.Register.square(2, 5, "q"), pulser.AnalogDevice)
        seq.declare_channel("ising", "rydberg_global")
        seq.add(pulser.Pulse.ConstantPulse(1000, np.pi/2, 0, 0), "ising")
        seq.delay(100, "ising")
        seq.add(pulser.Pulse(pulser.BlackmanWaveform(1000, np.pi/2), pulser.RampWaveform(1000, -np.pi/
```

```
In [4]: seq.draw(draw_register=True)
```

Register
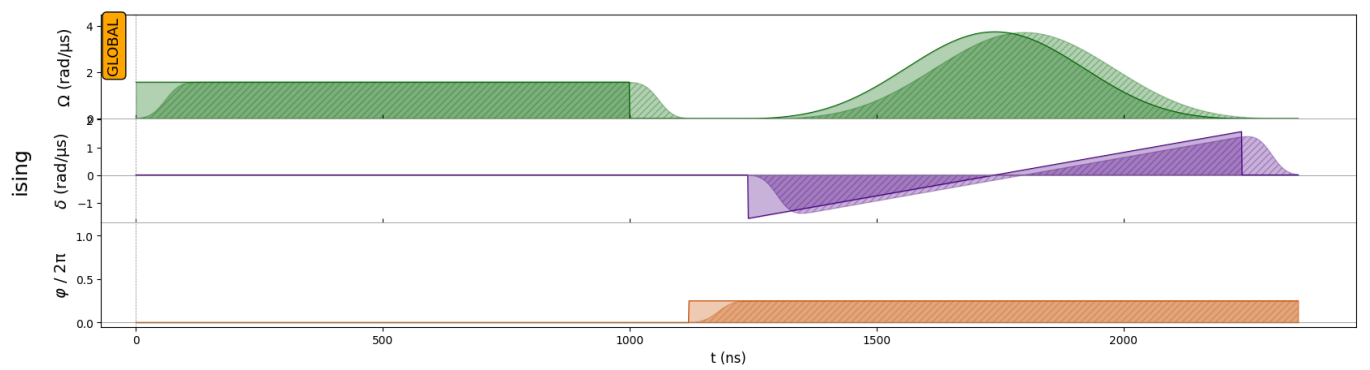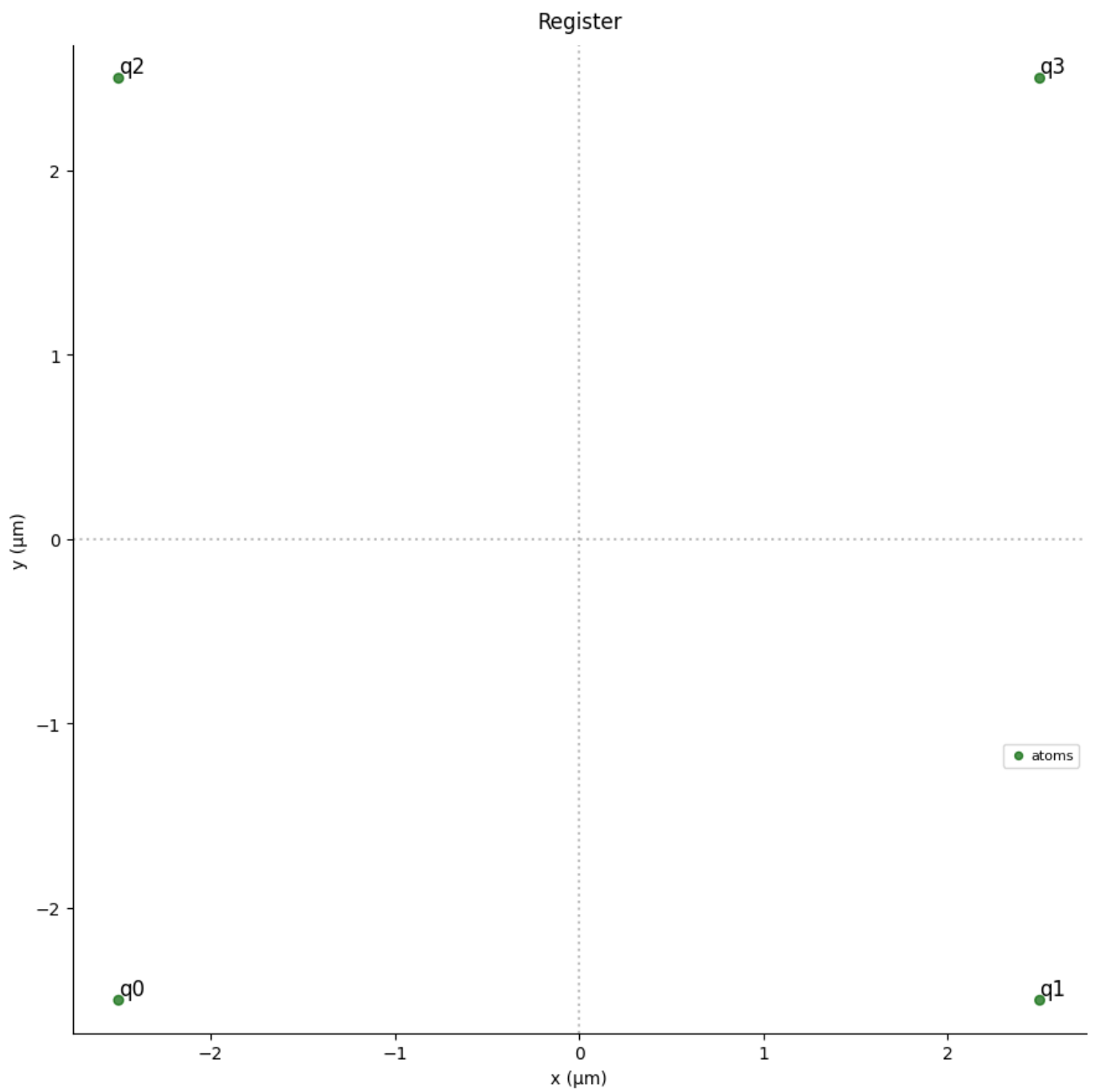
```
In [5]: backend = pulser_simulation.QutipBackend(seq)

In [6]: import qutip

In [7]: backend._sim_obj._hamiltonian._hamiltonian(0)
```

Out[7]: Quantum object: dims=[[2, 2, 2, 2], [2, 2, 2, 2]], shape=(16, 16), type='oper', dtype=CSR, isherm=True

$$\begin{pmatrix} 235.477 & 0.785 & 0.785 & 0 & 0.785 & \cdots & 0 & 0 & 0 & 0 & 0 \\ 0.785 & 117.738 & 0 & 0.785 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 \\ 0.785 & 0 & 117.738 & 0.785 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.785 & 0.785 & 55.406 & 0 & \cdots & 0.785 & 0 & 0 & 0 & 0 \\ 0.785 & 0 & 0 & 0 & 117.738 & \cdots & 0 & 0.785 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0.785 & 0 & \cdots & 0 & 0 & 0 & 0 & 0.785 \\ 0 & 0 & 0 & 0 & 0.785 & \cdots & 0 & 55.406 & 0.785 & 0.785 & 0 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0.785 & 0 & 0 & 0.785 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0.785 & 0 & 0 & 0.785 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0.785 & 0 & 0.785 & 0.785 & 0 \end{pmatrix}$$

In [8]:
```python
backend._sim_obj._hamiltonian._hamiltonian.copy()
```

Out[8]: QobjEvo: dims = [[2, 2, 2, 2], [2, 2, 2, 2]], shape = (16, 16), type = oper, superrep = None, isconstant = False, num_elements = 4

In [9]:
```python
%timeit backend.run()
```

45 ms ± 1 ms per loop (mean ± std. dev. of 7 runs, 10 loops each)

In [10]:
```python
mod_backend = pulser_simulation.QutipBackend(
    seq,
    pulser.EmulatorConfig(
        with_modulation=True
    )
)
```

In [11]:
```python
%timeit mod_backend.run()
```

46.6 ms ± 1.06 ms per loop (mean ± std. dev. of 7 runs, 10 loops each)

In [12]:
```python
t_backend = pulser_simulation.QutipBackend(
    seq,
    pulser.EmulatorConfig(
        with_modulation=True,
        noise_model=pulser.NoiseModel(
            temperature=0.1,
            runs=10,
            samples_per_run=1,
        )
    )
)
```

In [13]:
```python
%timeit t_backend.run()
```

1.5 s ± 27.9 ms per loop (mean ± std. dev. of 7 runs, 1 loop each)

In [14]:
```python
relax_backend = pulser_simulation.QutipBackend(
    seq,
    pulser.EmulatorConfig(
        with_modulation=True,
        noise_model=pulser.NoiseModel(
            relaxation_rate=0.1,
        )
    )
)
```

In [15]:
```python
relax_backend._sim_obj._hamiltonian._hamiltonian(0)
```

Out[15]: Quantum object: dims=[[2, 2, 2, 2], [2, 2, 2, 2]], shape=(16, 16), type='oper', dtype=CSR, isherm=True

$$
\begin{pmatrix}
235.477 & 0.004 & 0.004 & 0 & 0.004 & \cdots & 0 & 0 & 0 & 0 & 0 \\
0.004 & 117.738 & 0 & 0.004 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 \\
0.004 & 0 & 117.738 & 0.004 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 \\
0 & 0.004 & 0.004 & 55.406 & 0 & \cdots & 0.004 & 0 & 0 & 0 & 0 \\
0.004 & 0 & 0 & 0 & 117.738 & \cdots & 0 & 0.004 & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & 0 & 0 & 0.004 & 0 & \cdots & 0 & 0 & 0 & 0 & 0.004 \\
0 & 0 & 0 & 0 & 0.004 & \cdots & 0 & 55.406 & 0.004 & 0.004 & 0 \\
0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0.004 & 0 & 0 & 0.004 \\
0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0.004 & 0 & 0 & 0.004 \\
0 & 0 & 0 & 0 & 0 & \cdots & 0.004 & 0 & 0.004 & 0.004 & 0
\end{pmatrix}
$$

In [16]:
```python
relax_backend._sim_obj._hamiltonian._collapse_ops
```

```
Out[16]: [Quantum object: dims=[[2, 2, 2, 2], [2, 2, 2, 2]], shape=(16, 16), type='oper', dtype=CSR, i
         sherm=False
         Qobj data =
         [[0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.31622777 0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.31622777 0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.31622777 0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.31622777 0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.31622777 0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.31622777
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.31622777 0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.31622777 0.         0.         0.         0.
           0.         0.         0.         0.        ]],
          Quantum object: dims=[[2, 2, 2, 2], [2, 2, 2, 2]], shape=(16, 16), type='oper', dtype=CSR, i
         sherm=False
         Qobj data =
         [[0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.        ]
          [0.         0.         0.         0.         0.         0.
           0.         0.         0.         0.         0.         0.
```

```
      0.          0.          0.          0.          ]
    [0.31622777 0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          ]
    [0.          0.31622777 0.          0.          0.          0.
     0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          ]
    [0.          0.          0.31622777 0.          0.          0.
     0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          ]
    [0.          0.          0.          0.31622777 0.          0.
     0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          ]
    [0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          ]
    [0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          ]
    [0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          ]
    [0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          ]
    [0.          0.          0.          0.          0.          0.
     0.          0.          0.31622777 0.          0.          0.
     0.          0.          0.          0.          ]
    [0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.31622777 0.          0.
     0.          0.          0.          0.          ]
    [0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.31622777 0.
     0.          0.          0.          0.          ]
    [0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.          0.31622777
     0.          0.          0.          0.          ]],
 Quantum object: dims=[[2, 2, 2, 2], [2, 2, 2, 2]], shape=(16, 16), type='oper', dtype=CSR, i
sherm=False
 Qobj data =
 [[0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          ]
   [0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          ]
   [0.31622777 0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          ]
   [0.          0.31622777 0.          0.          0.          0.
    0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          ]
   [0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          ]
   [0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          ]
   [0.          0.          0.          0.          0.31622777 0.
    0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          ]
   [0.          0.          0.          0.          0.          0.31622777
    0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          ]
   [0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.          0.
```

```
    0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.31622777 0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.31622777 0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.31622777 0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.31622777 0.         0.         ]],
 Quantum object: dims=[[2, 2, 2, 2], [2, 2, 2, 2]], shape=(16, 16), type='oper', dtype=CSR, i
sherm=False
 Qobj data =
 [[0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.31622777 0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.31622777 0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.31622777 0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.31622777 0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.31622777 0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.31622777 0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
```

```
        0.31622777 0.          0.          0.          ]
       [0.          0.          0.          0.          0.          0.
        0.          0.          0.          0.          0.          0.
        0.          0.          0.          0.          ]
       [0.          0.          0.          0.          0.          0.
        0.          0.          0.          0.          0.          0.
        0.          0.          0.31622777 0.          ]]]
```

In [17]: `%timeit relax_backend.run()`

    97.1 ms ± 2.01 ms per loop (mean ± std. dev. of 7 runs, 10 loops each)

In [18]: `qutip.Qobj([[0, 0, 1], [0, 0, 1], [1, 1, 0]])`

Out[18]: Quantum object: dims=[[3], [3]], shape=(3, 3), type='oper', dtype=Dense, isherm=True

$$\begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix}$$

In [19]:
```
leakage_backend = pulser_simulation.QutipBackend(
    seq,
    pulser.EmulatorConfig(
        with_modulation=True,
        noise_model=pulser.NoiseModel(
            with_leakage=True,
            eff_noise_opers=[qutip.Qobj([[0, 0, 1], [0, 0, 1], [1, 1, 0]])],
            eff_noise_rates=[0.1]
        )
    )
)
```

```
[[0.+0.j 0.+0.j 1.+0.j]
 [0.+0.j 0.+0.j 1.+0.j]
 [1.+0.j 1.+0.j 0.+0.j]]
```

In [20]: `leakage_backend._sim_obj._hamiltonian._hamiltonian(0)`

Out[20]: Quantum object: dims=[[3, 3, 3, 3], [3, 3, 3, 3]], shape=(81, 81), type='oper', dtype=CSR, isherm=True

$$\begin{pmatrix} 235.477 & 0.004 & 0 & 0.004 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 \\ 0.004 & 117.738 & 0 & 0 & 0.004 & \cdots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 117.738 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 \\ 0.004 & 0 & 0 & 117.738 & 0.004 & \cdots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.004 & 0 & 0.004 & 55.406 & \cdots & 0 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & 0.004 & 0 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0.004 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

In [21]: `leakage_backend._sim_obj._hamiltonian._collapse_ops`

```
Out[21]:  [Quantum object: dims=[[3, 3, 3, 3], [3, 3, 3, 3]], shape=(81, 81), type='oper', dtype=CSR, i
          sherm=True
           Qobj data =
           [[0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]
            ...
            [0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]],
           Quantum object: dims=[[3, 3, 3, 3], [3, 3, 3, 3]], shape=(81, 81), type='oper', dtype=CSR, i
          sherm=True
           Qobj data =
           [[0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]
            ...
            [0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]],
           Quantum object: dims=[[3, 3, 3, 3], [3, 3, 3, 3]], shape=(81, 81), type='oper', dtype=CSR, i
          sherm=True
           Qobj data =
           [[0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]
            ...
            [0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]
            [0. 0. 0. ... 0. 0. 0.]],
           Quantum object: dims=[[3, 3, 3, 3], [3, 3, 3, 3]], shape=(81, 81), type='oper', dtype=CSR, i
          sherm=True
           Qobj data =
           [[0.         0.         0.31622777 ... 0.         0.         0.         ]
            [0.         0.         0.31622777 ... 0.         0.         0.         ]
            [0.31622777 0.31622777 0.         ... 0.         0.         0.         ]
            ...
            [0.         0.         0.         ... 0.         0.         0.31622777]
            [0.         0.         0.         ... 0.         0.         0.31622777]
            [0.         0.         0.         ... 0.31622777 0.31622777 0.         ]]]
```

In [22]: `%timeit leakage_backend.run()`

```
1.14 s ± 29.9 ms per loop (mean ± std. dev. of 7 runs, 1 loop each)
```