DSP — IDFT in Matrix Notation (W, K) + Signal Synthesis

We synthesize discrete-time signals by **IDFT in matrix form** for different values of (N). We explicitly build the matrices **(K)** (outer product of indices) and **(W)** (Fourier matrix), and plot the synthesized signals.

```
In [7]:
        import numpy as np
        import matplotlib.pyplot as plt
        def fourier matrices(N:int):
            k = np.arange(N).reshape(-1,1)
            mu = np.arange(N).reshape(1,-1)
            K = k * mu
            W = np.exp(1j * 2*np.pi * K / N)
            return K, W
        def idft_matrix(x_mu):
            x_mu = np.asarray(x_mu, dtype=complex).reshape(-1,1)
            N = x_mu.shape[0]
            K, W = fourier_matrices(N)
            x_k = (W @ x_mu) / N
            return x_k.flatten(), K, W
        def show_matrices(K, W, max_show=8):
            N = K.shape[0]
            m = min(N, max_show)
            print(f"N={N}\nK (top-left {m}x{m}):\n", K[:m,:m])
            Wr = np.round(W.real[:m,:m], 3)
            Wi = np.round(W.imag[:m,:m], 3)
            print(f"\nW (real, top-left {m}x{m}):\n", Wr)
            print(f"\nW (imag, top-left {m}x{m}):\n", Wi)
        def plot_signal(x_k, title="Synthesized signal x[k] (IDFT)"):
            k = np.arange(len(x_k))
            plt.figure(figsize=(8,3))
            plt.stem(k, x_k.real)
            plt.title(title + " - real part")
            plt.xlabel("k")
            plt.ylabel("Re{x[k]}")
            plt.tight layout()
            plt.show()
            if np.max(np.abs(x_k.imag)) > 1e-9:
                 plt.figure(figsize=(8,3))
                 plt.stem(k, x k.imag)
                 plt.title(title + " - imaginary part")
                 plt.xlabel("k")
                 plt.ylabel("Im{x[k]}")
                 plt.tight_layout()
                 plt.show()
```

1) Show K and W for N=4

```
In [8]: K4, W4 = fourier matrices(4)
        show matrices(K4, W4, max show=4)
       N=4
       K (top-left 4x4):
       [[0 0 0 0]]
       [0 1 2 3]
        [0 2 4 6]
       [0 3 6 9]]
       W (real, top-left 4x4):
       [[ 1. 1. 1. 1.]
       [ 1. 0. -1. -0.]
       [ 1. -1. 1. -1.]
       [ 1. -0. -1. 0.]]
       W (imag, top-left 4x4):
        [[ 0. 0. 0. 0.]
       [ 0. 1. 0. -1.]
       [ 0. 0. -0. 0.]
       [ 0. -1. 0. 1.]]
```

2) Variants — IDFT synthesis for the given (x_\mu)

```
In [9]: | variants = [
             [6, 2, 4, 3, 4, 5, 0, 0, 0, 0],
            [10, 5, 6, 6, 2, 4, 3, 4, 5, 0, 0, 0, 0],
            [6, 2, 4, 3, 4, 5, 0, 0, 0, 0],
            [6, 2, 4, 3, 4, 5, 0, 0, 0],
            [6, 4, 4, 5, 3, 4, 5, 0, 0, 0, 0],
            [7, 2, 4, 3, 4, 5, 0, 0, 0, 0],
            [6, 8, 2, 4, 3, 4, 5, 0, 0, 0],
             [6, 2, 4, 4, 4, 5, 0, 0, 0, 0],
            [6, 5, 4, 3, 4, 5, 0, 0, 0, 0],
            [6, 2, 4, 3, 4, 4, 0, 0, 0, 0],
        for i, xmu in enumerate(variants, start=1):
            xk, K, W = idft_matrix(xmu)
            print(f"\n=== Variant {i} - N={len(xmu)} ===")
            show_matrices(K, W, max_show=8)
            plot signal(xk, title=f"Variant {i}: N={len(xmu)}")
```

```
=== Variant 1 - N=10 ===
N = 10
K (top-left 8x8):
 [[0 0 0 0 0 0]]
      1
         2
            3 4 5 6 7]
            6 8 10 12 14]
         6 9 12 15 18 21]
      3
      4 8 12 16 20 24 28]
     5 10 15 20 25 30 35]
      6 12 18 24 30 36 42]
      7 14 21 28 35 42 49]]
W (real, top-left 8x8):
 [[ 1.
           1.
                   1.
                          1.
                                 1.
                                         1.
                                                1.
                                                       1.
 [ 1.
          0.809 0.309 -0.309 -0.809 -1.
                                              -0.809 -0.309]
          0.309 -0.809 -0.809
                                0.309 1.
                                               0.309 -0.809]
 1.
   1.
         -0.309 -0.809
                        0.809
                                0.309 -1.
                                               0.309
                                                     0.809]
         -0.809 0.309 0.309 -0.809 1.
                                              -0.809 0.309]
 [ 1.
 [ 1.
         -1.
                  1.
                        -1.
                                1.
                                       -1.
                                               1.
                                                     -1.
                                                            1
         -0.809 0.309 0.309 -0.809 1.
                                                      0.309]
 [ 1.
                                              -0.809
         -0.309 -0.809 0.809
                                0.309 -1.
                                               0.309
                                                      0.809]]
 [ 1.
W (imag, top-left 8x8):
                          0.
 [[ 0.
           0.
                  0.
                                 0.
                                         0.
                                                0.
                                                       0.
          0.588 0.951 0.951
                                0.588
                                       0.
                                              -0.588 -0.951]
 [ 0.
 [ 0.
          0.951 0.588 -0.588 -0.951 -0.
                                               0.951
                                                     0.588]
          0.951 -0.588 -0.588
                                0.951
                                              -0.951
                                                     0.588]
   0.
                                       0.
 [ 0.
          0.588 -0.951
                         0.951 -0.588 -0.
                                               0.588 -0.951]
                -0.
                               -0.
                         0.
                                       -0.
                                                      0.
 [ 0.
                                              -0.
 [ 0.
         -0.588 0.951 -0.951
                                0.588 -0.
                                              -0.588 0.951]
 [ 0.
         -0.951 0.588 0.588 -0.951
                                       0.
                                               0.951 -0.588]]
                                Variant 1: N=10 — real part
  2.5
  2.0
Re{x[k]}
  0.5
  0.0
                              Variant 1: N=10 — imaginary part
   1.0
   0.5
Im{x[k]}
   0.0
  -0.5
  -1.0
```

6

k

8

```
=== Variant 2 - N=13 ===
N = 13
K (top-left 8x8):
 [[0 0 0 0 0]]
      1
         2
            3 4 5 6 7]
            6 8 10 12 14]
      3
        6 9 12 15 18 21]
     4 8 12 16 20 24 28]
     5 10 15 20 25 30 35]
      6 12 18 24 30 36 42]
      7 14 21 28 35 42 49]]
W (real, top-left 8x8):
 [[ 1.
           1.
                  1.
                         1.
                                 1.
                                        1.
                                               1.
                                                      1.
 [ 1.
          0.885
                0.568 0.121 -0.355 -0.749 -0.971 -0.971]
          0.568 -0.355 -0.971 -0.749 0.121
                                              0.885
                                                     0.885]
 1.
   1.
          0.121 -0.971 -0.355
                               0.885 0.568 -0.749 -0.749]
         -0.355 -0.749 0.885
                               0.121 -0.971
                                             0.568
                                                    0.568]
 [ 1.
         -0.749 0.121 0.568 -0.971 0.885 -0.355 -0.355]
 [ 1.
         -0.971 0.885 -0.749
                               0.568 -0.355
                                              0.121
                                                     0.121
 [ 1.
         -0.971 0.885 -0.749 0.568 -0.355
 [ 1.
                                              0.121
                                                     0.121]]
W (imag, top-left 8x8):
                         0.
 [[ 0.
                  0.
                                 0.
                                        0.
                                               0.
          0.465
                 0.823 0.993
                               0.935
                                       0.663
                                              0.239 -0.239]
 [ 0.
 [ 0.
          0.823 0.935
                        0.239 -0.663 -0.993 -0.465
          0.993 0.239 -0.935 -0.465 0.823
                                              0.663 -0.663]
   0.
          0.935 -0.663 -0.465
                               0.993 -0.239 -0.823
                                                     0.823]
   0.
          0.663 -0.993  0.823 -0.239 -0.465
                                              0.935 -0.935]
 [ 0.
          0.239 -0.465  0.663 -0.823  0.935 -0.993  0.993]
 [ 0.
 [ 0.
         -0.239 0.465 -0.663 0.823 -0.935
                                              0.993 -0.993]]
                              Variant 2: N=13 — real part
  3
Re{x[k]}
  2
                                           6
                                           k
                             Variant 2: N=13 — imaginary part
   1.0
   0.5
|m{x[k]}
   0.0
  -0.5
  -1.0
                     ż
```

6

8

```
=== Variant 3 - N=10 ===
N = 10
K (top-left 8x8):
 [[0 0 0 0 0 0]]
      1
         2
            3 4 5 6 7]
            6 8 10 12 14]
         6 9 12 15 18 21]
      3
        8 12 16 20 24 28]
     5 10 15 20 25 30 35]
      6 12 18 24 30 36 42]
      7 14 21 28 35 42 49]]
W (real, top-left 8x8):
 [[ 1.
           1.
                   1.
                          1.
                                 1.
                                         1.
                                                1.
                                                       1.
 [ 1.
          0.809 0.309 -0.309 -0.809 -1.
                                              -0.809 -0.309]
          0.309 -0.809 -0.809
                                0.309 1.
                                               0.309 -0.809]
 1.
   1.
         -0.309 -0.809
                        0.809
                                0.309 -1.
                                               0.309
                                                     0.809]
         -0.809 0.309 0.309 -0.809 1.
                                              -0.809 0.309]
 [ 1.
 [ 1.
         -1.
                  1.
                        -1.
                                1.
                                       -1.
                                               1.
                                                     -1.
                                                            1
         -0.809 0.309 0.309 -0.809 1.
                                                      0.309]
 [ 1.
                                              -0.809
         -0.309 -0.809 0.809
                                0.309 -1.
                                               0.309
                                                      0.809]]
 [ 1.
W (imag, top-left 8x8):
                          0.
 [[ 0.
           0.
                  0.
                                 0.
                                         0.
                                                0.
                                                       0.
          0.588 0.951 0.951
                                0.588
                                       0.
                                              -0.588 -0.951]
 [ 0.
 [ 0.
          0.951 0.588 -0.588 -0.951 -0.
                                               0.951
                                                     0.588]
          0.951 -0.588 -0.588
                                0.951
                                              -0.951
                                                     0.588]
   0.
                                       0.
 [ 0.
          0.588 -0.951
                         0.951 -0.588 -0.
                                               0.588 -0.951]
                 -0.
                               -0.
                         0.
                                       -0.
                                                      0.
 [ 0.
                                              -0.
 [ 0.
         -0.588 0.951 -0.951
                                0.588 -0.
                                              -0.588 0.951]
 [ 0.
         -0.951 0.588 0.588 -0.951
                                       0.
                                               0.951 -0.588]]
                                Variant 3: N=10 — real part
  2.5
  2.0
Re{x[k]}
  0.5
  0.0
                              Variant 3: N=10 — imaginary part
   1.0
   0.5
Im{x[k]}
   0.0
  -0.5
  -1.0
```

6

k

8

```
=== Variant 4 - N=9 ===
N=9
K (top-left 8x8):
 [[0 0 0 0 0 0]]
      1
         2
            3 4 5 6 7]
            6 8 10 12 14]
      3
         6 9 12 15 18 21]
        8 12 16 20 24 28]
     5 10 15 20 25 30 35]
      6 12 18 24 30 36 42]
      7 14 21 28 35 42 49]]
W (real, top-left 8x8):
           1.
                   1.
 [[ 1.
                          1.
                                  1.
                                         1.
                                                1.
                                                        1.
                                                             ]
 [ 1.
          0.766 0.174 -0.5
                                -0.94
                                       -0.94
                                              -0.5
                                                       0.174
          0.174 -0.94 -0.5
                                0.766 0.766 -0.5
                                                      -0.94 ]
 1.
   1.
         -0.5
                 -0.5
                         1.
                                -0.5
                                       -0.5
                                               1.
                                                      -0.5 ]
         -0.94
                  0.766 -0.5
                                0.174 0.174 -0.5
 [ 1.
                                                       0.766]
                  0.766 -0.5
         -0.94
                                0.174 0.174 -0.5
 [ 1.
                                                       0.766]
                 -0.5
                                -0.5
         -0.5
                         1.
                                       -0.5
                                                1.
                                                      -0.5 ]
 [ 1.
                                                      -0.94 ]]
          0.174 -0.94
                        -0.5
                                 0.766 0.766 -0.5
 [ 1.
W (imag, top-left 8x8):
                          0.
 [[ 0.
           0.
                   0.
                                  0.
                                         0.
                                                0.
          0.643 0.985
                        0.866
                                0.342 -0.342 -0.866 -0.985]
 [ 0.
 [ 0.
          0.985 0.342 -0.866 -0.643 0.643
                                               0.866 -0.342]
          0.866 -0.866 -0.
                                 0.866 -0.866 -0.
                                                       0.866]
   0.
 [ 0.
          0.342 -0.643
                        0.866 -0.985 0.985 -0.866 0.643]
         -0.342   0.643   -0.866   0.985   -0.985   0.866   -0.643]
 [ 0.
 [ 0.
         -0.866 0.866 -0.
                                -0.866 0.866 -0.
                                                      -0.8661
         -0.985 -0.342 0.866
 [ 0.
                                0.643 -0.643 -0.866 0.342]]
                                 Variant 4: N=9 — real part
  2.5
  2.0 -
Re{x[k]}
1.0
  0.5
  0.0
                                                                        7
                           2
                                    3
                                             4
                                                      5
                                                               6
         0
                               Variant 4: N=9 — imaginary part
   0.5
Im{x[k]}
   0.0
  -0.5
                   i
                                                                        7
          Ó
                            2
                                    3
                                              4
                                                      5
                                                               6
```

```
=== Variant 5 - N=11 ===
N = 11
K (top-left 8x8):
 [[0 0 0 0 0 0]]
      1
         2
            3 4 5 6 7]
            6 8 10 12 14]
      3
        6 9 12 15 18 21]
     4 8 12 16 20 24 28]
     5 10 15 20 25 30 35]
      6 12 18 24 30 36 42]
      7 14 21 28 35 42 49]]
W (real, top-left 8x8):
 [[ 1.
           1.
                  1.
                         1.
                                 1.
                                        1.
                                               1.
                                                      1.
          0.841 0.415 -0.142 -0.655 -0.959 -0.959 -0.655]
 [ 1.
          0.415 -0.655 -0.959 -0.142 0.841 0.841 -0.142]
 1.
  1.
         -0.142 -0.959 0.415
                               0.841 -0.655 -0.655
                                                     0.841]
         -0.655 -0.142  0.841 -0.959  0.415  0.415 -0.959]
 [ 1.
         -0.959 0.841 -0.655 0.415 -0.142 -0.142 0.415]
 [ 1.
         -0.959 0.841 -0.655
                               0.415 -0.142 -0.142
                                                     0.415
 [ 1.
         -0.655 -0.142  0.841 -0.959  0.415
 [ 1.
                                              0.415 -0.959]]
W (imag, top-left 8x8):
                         0.
 [[ 0.
           0.
                  0.
                                 0.
                                        0.
                                               0.
          0.541 0.91
                        0.99
                                0.756 0.282 -0.282 -0.756]
 [ 0.
 [ 0.
                 0.756 -0.282 -0.99 -0.541
                                             0.541
          0.99 -0.282 -0.91
                                0.541 0.756 -0.756 -0.541]
   0.
          0.756 -0.99
                        0.541
                               0.282 -0.91
                                              0.91
                                                    -0.282]
 [ 0.
          0.282 -0.541 0.756 -0.91
                                       0.99
                                             -0.99
 [ 0.
                                                     0.91
         -0.282 0.541 -0.756
                               0.91
                                     -0.99
                                              0.99
                                                    -0.91 ]
 [ 0.
 [ 0.
         -0.756 0.99 -0.541 -0.282 0.91
                                            -0.91
                                                     0.282]]
                               Variant 5: N=11 — real part
  2.5
  2.0 -
% 1.5
1.0
  0.5
  0.0
                                                                              10
                             Variant 5: N=11 — imaginary part
   1.0
   0.5
lm{x[k]}
   0.0
  -0.5
  -1.0
```

4

k

```
=== Variant 6 - N=10 ===
N = 10
K (top-left 8x8):
 [[0 0 0 0 0 0]]
      1
         2
            3 4 5 6 7]
            6 8 10 12 14]
      3
         6 9 12 15 18 21]
        8 12 16 20 24 28]
     5 10 15 20 25 30 35]
      6 12 18 24 30 36 42]
      7 14 21 28 35 42 49]]
W (real, top-left 8x8):
 [[ 1.
           1.
                   1.
                          1.
                                 1.
                                         1.
                                                1.
                                                        1.
 [ 1.
          0.809 0.309 -0.309 -0.809 -1.
                                              -0.809 -0.309]
          0.309 -0.809 -0.809
                                0.309 1.
                                               0.309 -0.809]
 1.
   1.
         -0.309 -0.809
                        0.809
                                0.309 -1.
                                               0.309
                                                      0.809]
         -0.809 0.309 0.309 -0.809 1.
                                              -0.809 0.309]
 [ 1.
 [ 1.
         -1.
                  1.
                        -1.
                                1.
                                       -1.
                                               1.
                                                      -1.
                                                            1
         -0.809 0.309 0.309 -0.809 1.
                                                       0.309]
 [ 1.
                                              -0.809
                                                      0.809]]
         -0.309 -0.809 0.809
                                0.309 -1.
                                               0.309
 [ 1.
W (imag, top-left 8x8):
                          0.
 [[ 0.
           0.
                   0.
                                 0.
                                         0.
                                                0.
                                                        0.
          0.588 0.951 0.951
                                0.588
                                        0.
                                              -0.588 -0.951]
 [ 0.
 [ 0.
          0.951 0.588 -0.588 -0.951 -0.
                                               0.951
                                                      0.588]
          0.951 -0.588 -0.588
                                0.951
                                              -0.951
                                                      0.588]
   0.
                                        0.
 [ 0.
          0.588 -0.951
                         0.951 -0.588 -0.
                                               0.588 -0.951]
                 -0.
                               -0.
                         0.
                                       -0.
                                                       0.
 [ 0.
                                              -0.
 [ 0.
         -0.588 0.951 -0.951
                                0.588 -0.
                                              -0.588 0.951]
 [ 0.
         -0.951 0.588 0.588 -0.951
                                       0.
                                               0.951 -0.588]]
                                Variant 6: N=10 — real part
  2.5
  2.0
% 1.5 [k] 1.0
  0.5
  0.0
                              Variant 6: N=10 — imaginary part
   1.0
   0.5
Im{x[k]}
   0.0
  -0.5
  -1.0
```

6

k

8

```
=== Variant 7 - N=10 ===
N = 10
K (top-left 8x8):
 [[00000
      1
         2
            3 4 5 6 7]
            6 8 10 12 14]
      3
         6
           9 12 15 18 21]
        8 12 16 20 24 28]
      5 10 15 20 25 30 35]
      6 12 18 24 30 36 42]
      7 14 21 28 35 42 49]]
W (real, top-left 8x8):
 [[ 1.
           1.
                   1.
                          1.
                                 1.
                                         1.
                                                1.
                                                        1.
 [ 1.
          0.809 0.309 -0.309 -0.809 -1.
                                              -0.809 -0.309]
          0.309 -0.809 -0.809
                                0.309
                                               0.309 -0.809]
 1.
                                      1.
   1.
         -0.309 -0.809
                        0.809
                                0.309 -1.
                                               0.309
                                                      0.809]
         -0.809 0.309 0.309 -0.809
 [ 1.
                                      1.
                                              -0.809 0.309]
 [ 1.
         -1.
                  1.
                        -1.
                                1.
                                       -1.
                                               1.
                                                      -1.
         -0.809 0.309 0.309 -0.809
                                                      0.309]
 [ 1.
                                      1.
                                              -0.809
         -0.309 -0.809 0.809
                                0.309 -1.
                                               0.309
                                                      0.809]]
 [ 1.
W (imag, top-left 8x8):
                          0.
 [[ 0.
           0.
                   0.
                                 0.
                                         0.
                                                0.
                                                        0.
          0.588 0.951 0.951
                                0.588
                                              -0.588 -0.951]
 [ 0.
                                        0.
 [ 0.
          0.951 0.588 -0.588 -0.951 -0.
                                               0.951
                                                      0.588]
          0.951 -0.588 -0.588
                                0.951
                                              -0.951
                                                      0.588]
   0.
                                        0.
  0.
          0.588 -0.951
                         0.951 -0.588 -0.
                                               0.588 -0.951]
                 -0.
                               -0.
                         0.
                                       -0.
                                                      0.
 [ 0.
                                              -0.
 [ 0.
         -0.588
                0.951 -0.951 0.588 -0.
                                              -0.588
                                                      0.951]
 [ 0.
         -0.951 0.588 0.588 -0.951
                                               0.951 -0.588]]
                                       0.
                               Variant 7: N=10 — real part
  3
Re{x[k]}
  0
       Ó
                                            k
                              Variant 7: N=10 — imaginary part
   1.0
   0.5
m{x[k]}
   0.0
  -0.5
  -1.0
                          2
```

```
=== Variant 8 - N=10 ===
N = 10
K (top-left 8x8):
 [[000000
      1
         2
            3 4 5 6 7]
            6 8 10 12 14]
         6 9 12 15 18 21]
      3
        8 12 16 20 24 28]
      5 10 15 20 25 30 35]
      6 12 18 24 30 36 42]
      7 14 21 28 35 42 49]]
W (real, top-left 8x8):
 [[ 1.
           1.
                   1.
                          1.
                                  1.
                                         1.
                                                1.
                                                        1.
 [ 1.
          0.809 0.309 -0.309 -0.809 -1.
                                              -0.809 -0.309]
 0.309 -0.809 -0.809
                                0.309 1.
                                               0.309 -0.809]
   1.
   1.
         -0.309 -0.809
                        0.809
                                0.309 -1.
                                               0.309
                                                      0.809]
         -0.809 0.309 0.309 -0.809 1.
                                              -0.809 0.309]
 [ 1.
 [ 1.
         -1.
                  1.
                        -1.
                                1.
                                       -1.
                                               1.
                                                      -1.
                                                            1
         -0.809 0.309 0.309 -0.809 1.
                                                       0.309]
 [ 1.
                                              -0.809
         -0.309 -0.809 0.809
                                0.309 -1.
                                               0.309
                                                      0.809]]
 [ 1.
W (imag, top-left 8x8):
                          0.
 [[ 0.
           0.
                   0.
                                  0.
                                         0.
                                                0.
                                                        0.
          0.588 0.951 0.951
                                0.588
                                        0.
                                              -0.588 -0.951]
 [ 0.
 [ 0.
          0.951 0.588 -0.588 -0.951 -0.
                                               0.951
                                                      0.588]
          0.951 -0.588 -0.588
                                0.951
                                              -0.951
                                                      0.588]
   0.
                                        0.
 [ 0.
          0.588 -0.951
                         0.951 -0.588 -0.
                                               0.588 -0.951]
                 -0.
                                -0.
                         0.
                                       -0.
                                                       0.
 [ 0.
                                              -0.
 [ 0.
         -0.588 0.951 -0.951
                                0.588 -0.
                                              -0.588 0.951]
 [ 0.
         -0.951 0.588 0.588 -0.951
                                       0.
                                               0.951 -0.588]]
                                Variant 8: N=10 — real part
  2.5
  2.0
% 1.5 
1.0 
1.0
  0.5
  0.0
         Ó
                                         4
                                                        6
                              Variant 8: N=10 — imaginary part
   1.0
   0.5
|m{x[k]}
   0.0
  -0.5
  -1.0
                          2
                                                         6
                                                                         8
```

k

```
=== Variant 9 - N=10 ===
N = 10
K (top-left 8x8):
 [[000000
      1
         2
            3 4 5 6 7]
            6 8 10 12 14]
      3
         6 9 12 15 18 21]
        8 12 16 20 24 28]
     5 10 15 20 25 30 35]
      6 12 18 24 30 36 42]
      7 14 21 28 35 42 49]]
W (real, top-left 8x8):
 [[ 1.
           1.
                   1.
                          1.
                                 1.
                                        1.
                                                1.
                                                       1.
 [ 1.
          0.809 0.309 -0.309 -0.809 -1.
                                              -0.809 -0.309]
          0.309 -0.809 -0.809
                                0.309 1.
                                               0.309 -0.809]
 1.
   1.
         -0.309 -0.809
                        0.809
                                0.309 -1.
                                               0.309
                                                     0.809]
         -0.809 0.309 0.309 -0.809 1.
                                              -0.809 0.309]
 [ 1.
 [ 1.
         -1.
                 1.
                        -1.
                                1.
                                       -1.
                                               1.
                                                     -1.
         -0.809 0.309 0.309 -0.809 1.
                                                      0.309]
 [ 1.
                                              -0.809
         -0.309 -0.809 0.809
                                0.309 -1.
                                               0.309
                                                      0.809]]
 [ 1.
W (imag, top-left 8x8):
                          0.
 [[ 0.
           0.
                   0.
                                 0.
                                        0.
                                                0.
                                                       0.
          0.588 0.951 0.951
                                0.588
                                       0.
                                              -0.588 -0.951]
 [ 0.
 [ 0.
          0.951 0.588 -0.588 -0.951 -0.
                                               0.951
                                                     0.588]
          0.951 -0.588 -0.588
                                0.951
                                              -0.951
                                                     0.588]
   0.
                                       0.
 [ 0.
          0.588 -0.951
                        0.951 -0.588 -0.
                                               0.588 -0.951]
                -0.
                               -0.
                         0.
                                       -0.
                                                      0.
 [ 0.
                                              -0.
 [ 0.
         -0.588 0.951 -0.951
                                0.588 -0.
                                              -0.588 0.951]
 [ 0.
         -0.951 0.588 0.588 -0.951
                                       0.
                                               0.951 -0.588]]
                                Variant 9: N=10 — real part
  2.5
  2.0
Re{x[k]}
  0.5
  0.0
                              Variant 9: N=10 — imaginary part
   1.0
   0.5
lm{x[k]}
   0.0
  -0.5
  -1.0
                         2
                                                                        8
```

6

k

```
=== Variant 10 - N=10 ===
N = 10
K (top-left 8x8):
 [[0 0 0 0 0 0]]
      1
         2
            3 4 5 6 7]
            6 8 10 12 14]
         6 9 12 15 18 21]
      3
        8 12 16 20 24 28]
      5 10 15 20 25 30 35]
      6 12 18 24 30 36 42]
      7 14 21 28 35 42 49]]
W (real, top-left 8x8):
 [[ 1.
           1.
                   1.
                          1.
                                 1.
                                         1.
                                                1.
                                                        1.
 [ 1.
          0.809 0.309 -0.309 -0.809 -1.
                                              -0.809 -0.309]
          0.309 -0.809 -0.809
                                0.309 1.
                                               0.309 -0.809]
 1.
   1.
         -0.309 -0.809
                        0.809
                                0.309 -1.
                                               0.309
                                                      0.809]
         -0.809 0.309 0.309 -0.809 1.
                                              -0.809 0.309]
 [ 1.
 [ 1.
         -1.
                  1.
                        -1.
                                1.
                                       -1.
                                               1.
                                                      -1.
                                                            1
         -0.809 0.309 0.309 -0.809 1.
                                                      0.309]
 [ 1.
                                              -0.809
                                                      0.809]]
         -0.309 -0.809 0.809
                                0.309 -1.
                                               0.309
 [ 1.
W (imag, top-left 8x8):
                          0.
 [[ 0.
           0.
                   0.
                                 0.
                                         0.
                                                0.
                                                        0.
          0.588 0.951 0.951
                                0.588
                                        0.
                                              -0.588 -0.951]
 [ 0.
 [ 0.
          0.951 0.588 -0.588 -0.951 -0.
                                               0.951
                                                      0.588]
          0.951 -0.588 -0.588
                                0.951
                                              -0.951
                                                      0.588]
   0.
                                        0.
   0.
          0.588 -0.951
                         0.951 -0.588 -0.
                                               0.588 -0.951]
                 -0.
                               -0.
                         0.
                                       -0.
                                                      0.
 [ 0.
                                              -0.
 [ 0.
         -0.588 0.951 -0.951
                                0.588 -0.
                                              -0.588 0.951]
 [ 0.
         -0.951 0.588 0.588 -0.951
                                       0.
                                               0.951 -0.588]]
                               Variant 10: N=10 - real part
  2.0
Re{x[K]}
  0.5
  0.0
                             Variant 10: N=10 — imaginary part
   1.0
   0.5
Im{x[k]}
   0.0
  -0.5
  -1.0
```

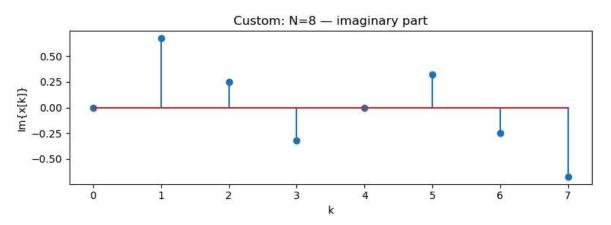
6

k

8

3) Playground — try your own vector x_mu

```
In [10]: xmu custom = [8, 2, 4, 0, 0, 0, 0, 0]
                                                    # N=8 example
          xk, K, W = idft_matrix(xmu_custom)
          show matrices(K, W, max show=8)
          plot_signal(xk, title=f"Custom: N={len(xmu_custom)}")
        N=8
        K (top-left 8x8):
         [[ 0 0 0 0 0 0 0]
         [01234567]
                    6 8 10 12 14]
                  6 9 12 15 18 21]
              4 8 12 16 20 24 28]
              5 10 15 20 25 30 35]
              6 12 18 24 30 36 42]
         [ 0 7 14 21 28 35 42 49]]
        W (real, top-left 8x8):
         [[ 1.
                    1.
                           1.
                                   1.
                                                  1.
                                                         1.
                                                                 1. ]
                                          1.
         [ 1.
                   0.707
                                 -0.707 -1.
                                                -0.707 -0.
                                                                0.707]
                   0.
                                 -0.
                                                       -1.
         [ 1.
                         -1.
                                         1.
                                                 0.
                                                               -0.
                  -0.707 -0.
                                  0.707 -1.
                                                 0.707
                                                        0.
                                                               -0.707]
         [ 1.
           1.
                  -1.
                          1.
                                         1.
                                                -1.
                                                        1.
                                                               -1.
                                 -1.
           1.
                  -0.707
                          0.
                                  0.707 -1.
                                                 0.707 -0.
                                                               -0.707]
                  -0.
                         -1.
                                         1.
                                                       -1.
                                                               -0.
         [ 1.
                                  0.
                                                -0.
                   0.707 -0.
         [ 1.
                                 -0.707 -1.
                                                -0.707 -0.
                                                                0.707]]
        W (imag, top-left 8x8):
         [[ 0.
                    0.
                                   0.
                                          0.
                                                  0.
                                                                 0.
         [ 0.
                   0.707
                                  0.707
                                         0.
                                                -0.707 -1.
                                                               -0.707]
                          1.
           0.
                          0.
                                        -0.
                                                 1.
                                                        0.
                                                               -1.
                                                                     ]
                   0.707 -1.
                                                -0.707
                                  0.707
                                         0.
                                                               -0.707]
         [ 0.
                                                       1.
         [ 0.
                   0.
                         -0.
                                  0.
                                        -0.
                                                       -0.
                                                 0.
                                                                0.
           0.
                  -0.707
                          1.
                                 -0.707
                                         0.
                                                 0.707 -1.
                                                                0.707]
                          0.
                                                        0.
         [ 0.
                  -1.
                                  1.
                                        -0.
                                                -1.
                                                                1.
                                                                     1
         [ 0.
                  -0.707 -1.
                                 -0.707
                                                 0.707
                                                        1.
                                                                0.707]]
                                          Custom: N=8 — real part
          1.5
        Re{x[k]}
          1.0
           0.5
           0.0
                                                           4
                                                                     5
```



In []: