Direct Digital Synthesis: solution

Introduction to digital Low-Level Radio Frequency Controls in Accelerators

Lab 6

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Contents

1 Solutions

1.1 Simulate DDS verilog module

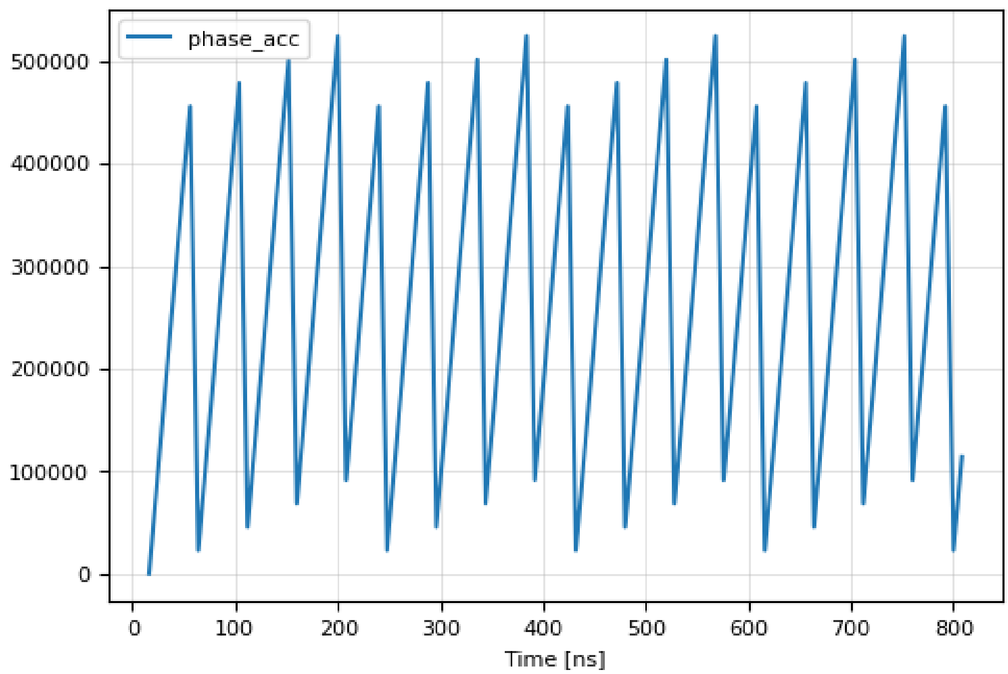
Plot the time domain waveform and its power spectrum density.

[1]:
```
!make clean ph_acc.csv
```

```
rm -f ph_acc.csv dds.pdf dds_solution.pdf ph_acc.vcd ph_acc_tb
iverilog  -Wall -Wno-timescale -o ph_acc_tb ph_acc_tb.v ph_acc.v
vvp -N ph_acc_tb +of=ph_acc.csv
Recording output to file:           ph_acc.csv
phase_step_h:   182361
phase_step_l:      178
modulo:              2
Time: 65544 ns. cc =  8193. Done.
```

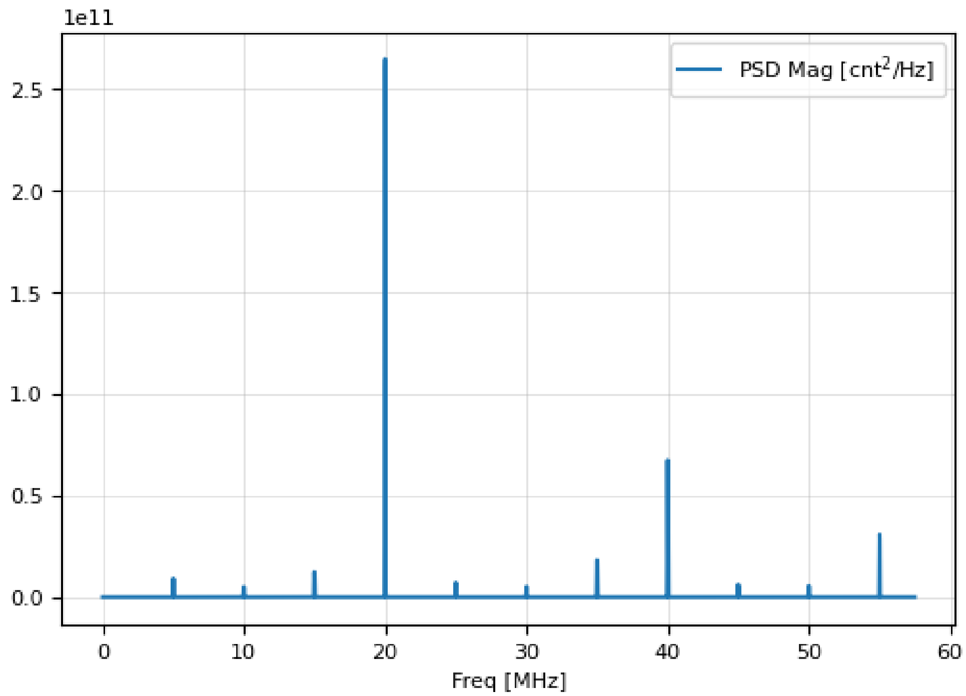
[2]:
```
%matplotlib inline
from numpy.polynomial import polynomial
from scipy import signal
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt

from dds import calc_dds, reg2freq

plt.rcParams['figure.figsize'] = [6, 4]
plt.rcParams['axes.grid'] = True
plt.rcParams['axes.grid.which'] = "both"
plt.rcParams['grid.linewidth'] = 0.5
plt.rcParams['grid.alpha'] = 0.5
plt.rcParams['font.size'] = 8
```

[3]:
```
df = pd.read_csv('ph_acc.csv')
df[:100].plot(x='Time [ns]');
```



[4]:
```
fs = 480 * 23 / 24 / 4  # MHz
f, psd = signal.periodogram(
    df['phase_acc'], fs, 'flattop', scaling='density')
df_psd = pd.DataFrame(
    {'Freq [MHz]': f, 'PSD Mag [cnt$^2$/Hz]': psd})
df_psd.plot(x='Freq [MHz]');
print(f'Peak frequency: {f[np.argmax(psd)]:.3f} MHz')
```

```
Peak frequency: 20.004 MHz
```



1.2 Derive a different setting for LBNL ALS-U LLRF

Calcuate new values of ph, pl and modulo for digital LO DDS.

[5]:
```python
num, den = 4, 11
fclk = 500e6 * 11 / 48  # Hz

ph, pl, modulo = calc_dds(num, den)
print(f'ph: {ph}, pl: {pl}, modulo: {modulo}')
```

```
ph: 381300, pl: 1488, modulo: 4
```

[6]:
```python
fdds = reg2freq(ph, pl, modulo, fclk)
print(f'DDS freq: {fdds/1e6:.3f} MHz')
```

```
major resolution:  109.275 Hz
minor resolution:  0.027 Hz
modulo resolution: 0.010 Hz
DDS freq: 41.667 MHz
```

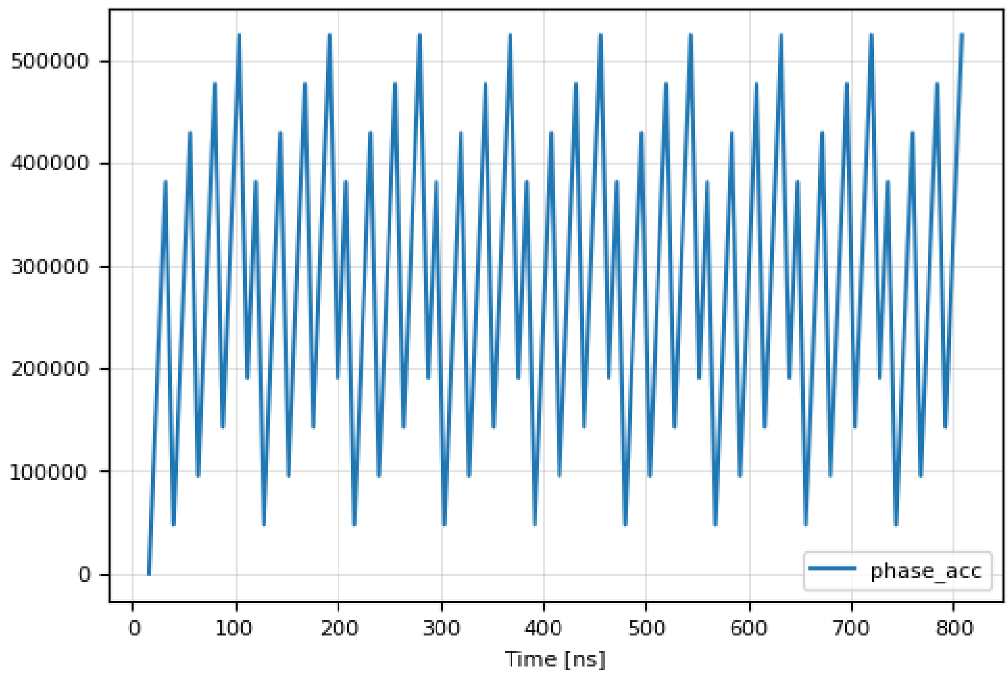
1.3 Rerun the DDS verilog simulation

Re-run using your settings and check the new spectrum.

[7]:
```
!vvp -N ph_acc_tb +of=ph_acc.csv +ph=381300 +pl=1488 +modulo=4
```

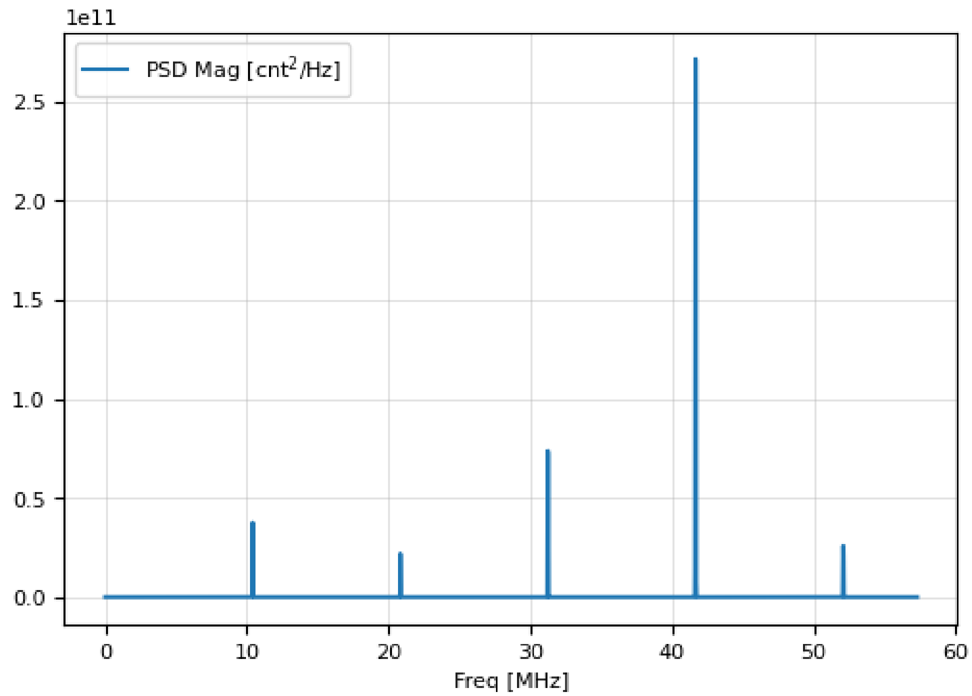
```
Recording output to file:           ph_acc.csv
phase_step_h:   381300
phase_step_l:     1488
modulo:              4
Time: 65544 ns. cc =  8193. Done.
```

[8]:
```
df = pd.read_csv('ph_acc.csv')
df[:100].plot(x='Time [ns]');
```



[9]:
```
fs = fclk / 1e6  # MHz
f, psd = signal.periodogram(df['phase_acc'], fs, 'flattop',␣
 ↪scaling='density')
df_psd = pd.DataFrame({'Freq [MHz]': f, 'PSD Mag [cnt$^2$/Hz]': psd})
df_psd.plot(x='Freq [MHz]');
print(f'Peak frequency: {f[np.argmax(psd)]:.3f} MHz')
```

```
Peak frequency: 41.668 MHz
```



1.4 Build complete DDS with CORDIC

```
wire signed [18:0] cosd, sind;
wire [18:0] dds_phase_acc;
ph_acc dds_lo (
    .clk              (clk),
    .reset            (reset),
    .en               (1'b1),
    .phase_acc        (dds_phase_acc),
    .phase_step_h     (dds_phase_step[31:12]),
    .phase_step_l     (dds_phase_step[11: 0]),
    .modulo           (dds_modulo)
);

cordicg_b22 #(.nstg(20), .width(18)) dds_cordicg_i(
    .clk              (clk),
    .opin             (2'b00),
    .xin              (18'd74840),
    .yin              (18'd0),
    .phasein          (dds_phase_acc),
    .xout             (cosd),
    .yout             (sind)
```

```
);
```