Feedback Control

Introduction to digital Low-Level Radio Frequency Controls in Accelerators

Lab 11

Qiang Du

US Particle Accelerator School
Janurary 23 – 27, 2023

Contents

[7]:

```
%matplotlib inline
from matplotlib import pyplot as plt
from scipy import signal
import pandas as pd
import numpy as np
from epics import PV, caget, caput

import os
os.environ['EPICS_CA_ADDR_LIST'] = 'localhost'
os.environ['EPICS_CA_AUTO_ADDR_LIST'] = 'NO'

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
```

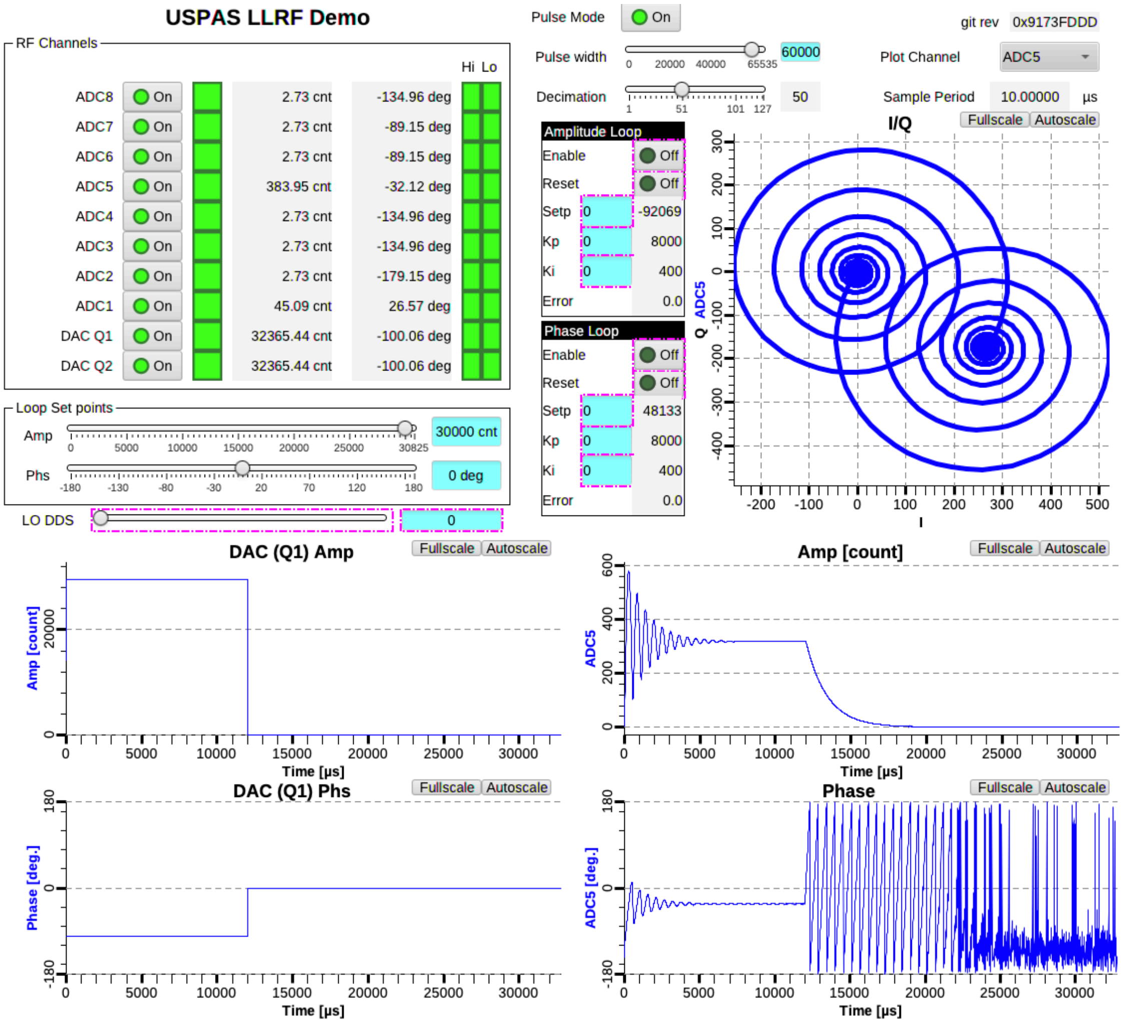
[8]:

```
caput('USPAS:LLRF:Loop:AmpSetp', 30000)
caput('USPAS:LLRF:reg_pulse_mode', 1)
caput('USPAS:LLRF:reg_pulse_high_len', 60000)
caput('USPAS:LLRF:ACQ_DECIM', 50)
```

[8]:

```
1
```

The ADC5 waveform will show the step response of the crystal. It is expected to have a result like the following screenshot.



ADC8	● On	🟩	2.73 cnt	-134.96 deg	🟩 🟩
ADC7	● On	🟩	2.73 cnt	-89.15 deg	🟩 🟩
ADC6	● On	🟩	2.73 cnt	-89.15 deg	🟩 🟩
ADC5	● On	🟩	383.95 cnt	-32.12 deg	🟩 🟩
ADC4	● On	🟩	2.73 cnt	-134.96 deg	🟩 🟩
ADC3	● On	🟩	2.73 cnt	-134.96 deg	🟩 🟩
ADC2	● On	🟩	2.73 cnt	-179.15 deg	🟩 🟩
ADC1	● On	🟩	45.09 cnt	26.57 deg	🟩 🟩
DAC Q1	● On	🟩	32365.44 cnt	-100.06 deg	🟩 🟩
DAC Q2	● On	🟩	32365.44 cnt	-100.06 deg	🟩 🟩

Amp 30000 cnt (slider 0 – 30825)
Phs 0 deg (slider -180 – 180)
LO DDS 0

Pulse Mode ● On
Pulse width 60000 (slider 0 – 65535)
Decimation 50 (slider 1 – 127)
git rev 0x9173FDDD
Plot Channel ADC5
Sample Period 10.00000 µs

Amplitude Loop		
Enable		● Off
Reset		● Off
Setp	0	-92069
Kp	0	8000
Ki	0	400
Error		0.0

Phase Loop		
Enable		● Off
Reset		● Off
Setp	0	48133
Kp	0	8000
Ki	0	400
Error		0.0

Explain the reason of ringing of the ADC5 amplitude and phase waveforms. Explain the spirals in IQ waveform plot.

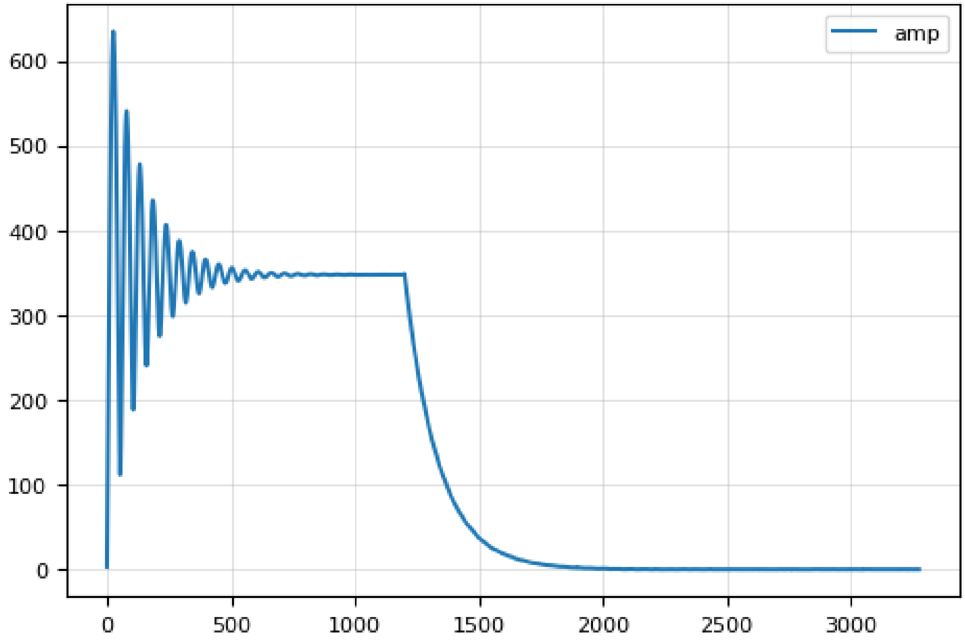
0.1 Find cavity detune through falling edge analysis

```
[9]: fs = 1e6 / PV('USPAS:LLRF:ACQ_SAMP_PERIOD').value
pv_twf = PV('USPAS:LLRF:CavCel:TWF')
pv_awf = PV('USPAS:LLRF:CavCel:AWF')
pv_pwf = PV('USPAS:LLRF:CavCel:PWF')
pv_iwf = PV('USPAS:LLRF:CavCel:IWF')
pv_qwf = PV('USPAS:LLRF:CavCel:QWF')

df = pd.DataFrame({
    'T [µs]': pv_twf.value,
    'amp': pv_awf.value,
    'phs': pv_pwf.value,
    'i': pv_iwf.value, 'q': pv_qwf.value})
df.set_index('T [µs]');
```

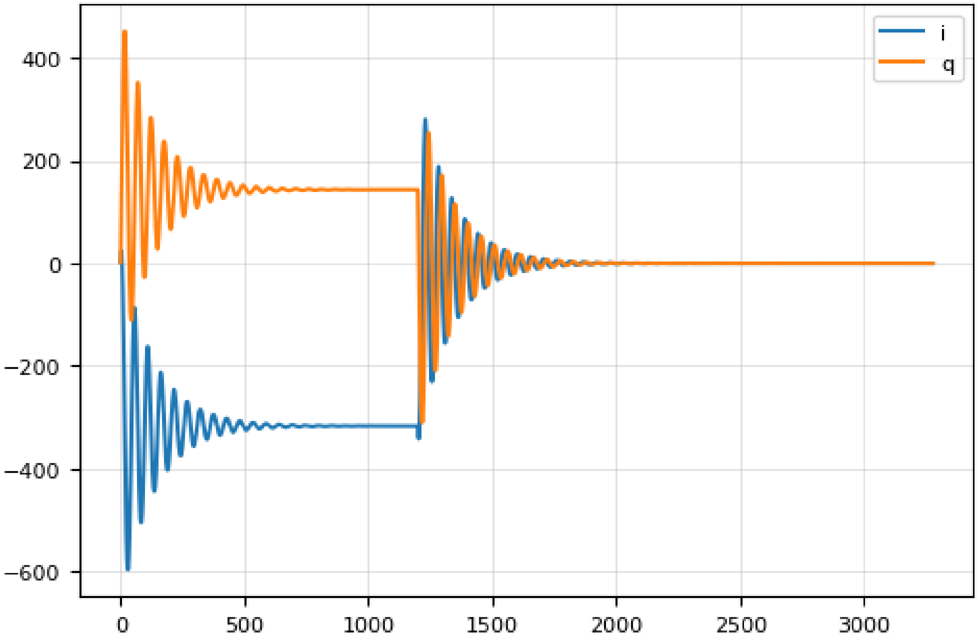
[10]:
```
df[['amp']].plot()
```

[10]:
```
<AxesSubplot: >
```



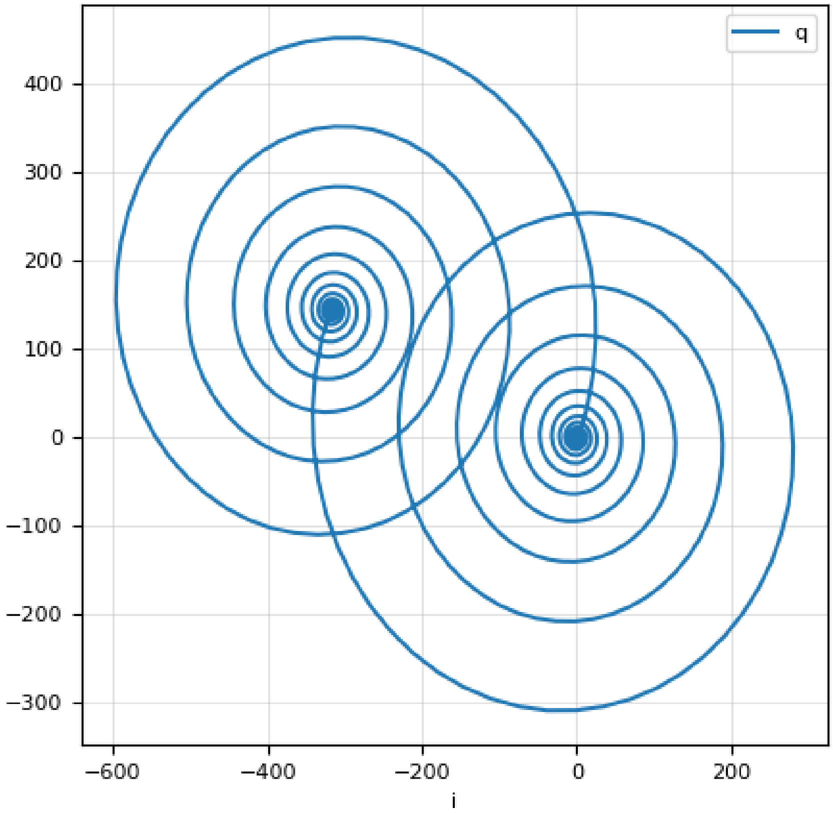
[11]:
```
df[['i', 'q']].plot()
```

[11]:
```
<AxesSubplot: >
```



```
[12]: df[['i', 'q']].plot(x='i', figsize=(5,5))
```

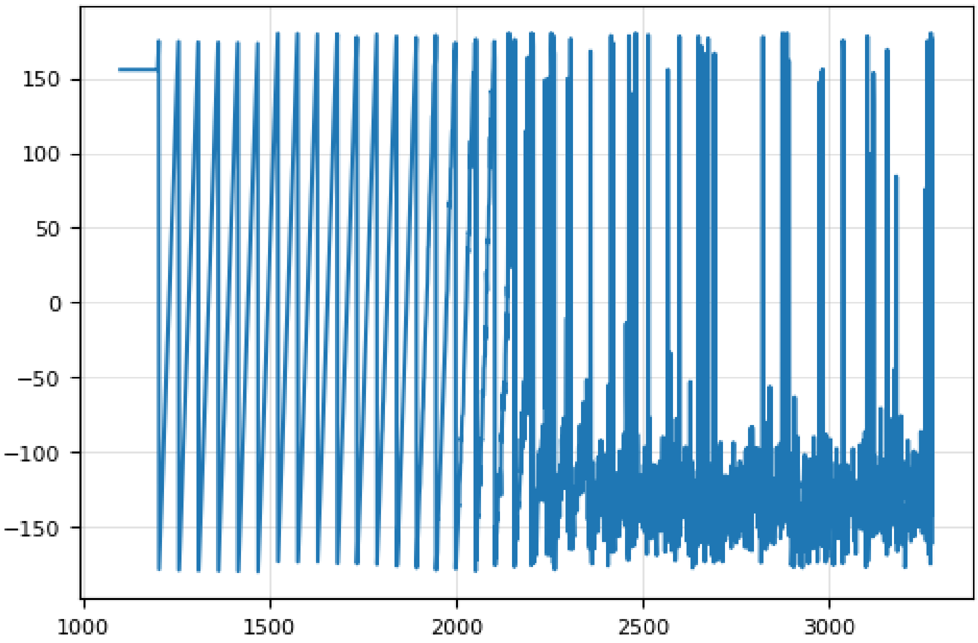
```
[12]: <AxesSubplot: xlabel='i'>
```



0.2 Extract detune frequency from falling edge

Confirm falling edge starts from 1200 µs:

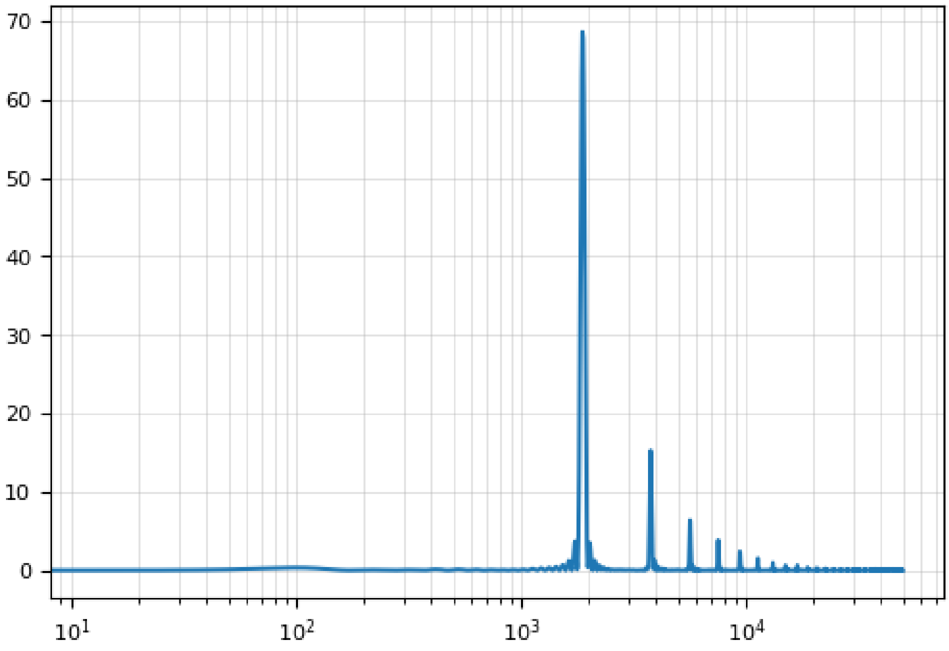
[13]:
```
df[1100:]['phs'].plot();
```



[14]:
```
fall_wf = df[1200:2200]['phs']
f, pxx_den = signal.periodogram(fall_wf, fs, nfft=8192)
f_peak = f[np.argmax(pxx_den)]
```

[15]:
```
plt.semilogx(f, pxx_den)
print(f'Peak freq: {f_peak:.2f} Hz')
```

```
Peak freq: 1879.88 Hz
```



Therefore cavity detune is at 1.8 kHz.

From crystal characterization lab, we know the resoance frequency is around 19.998 MHz, so this measurement confirms that the exact frequency is at 19.9982 MHz.

0.3 Measure the crystal bandwidth.

Compare the results to the one you measured on the first day.

0.4 Adjust LLRF LO DDS to *tune* crystal

[16]:
```
import sys
sys.path.append('..')
from dds.dds import calc_dds, reg2freq
```

[17]:
```
num = 4 * (1 - f_peak / 20e6)  # offset from 4
ph, pl, modulo = calc_dds(num, 23)
fdds = reg2freq(ph, pl, modulo, 115e6)
print(f'New DDS freq: {fdds/1e6:.3f} MHz')
```

```
major resolution:  109.673 Hz
minor resolution:  0.027 Hz
modulo resolution: 0.024 Hz
New DDS freq: 19.998 MHz
```

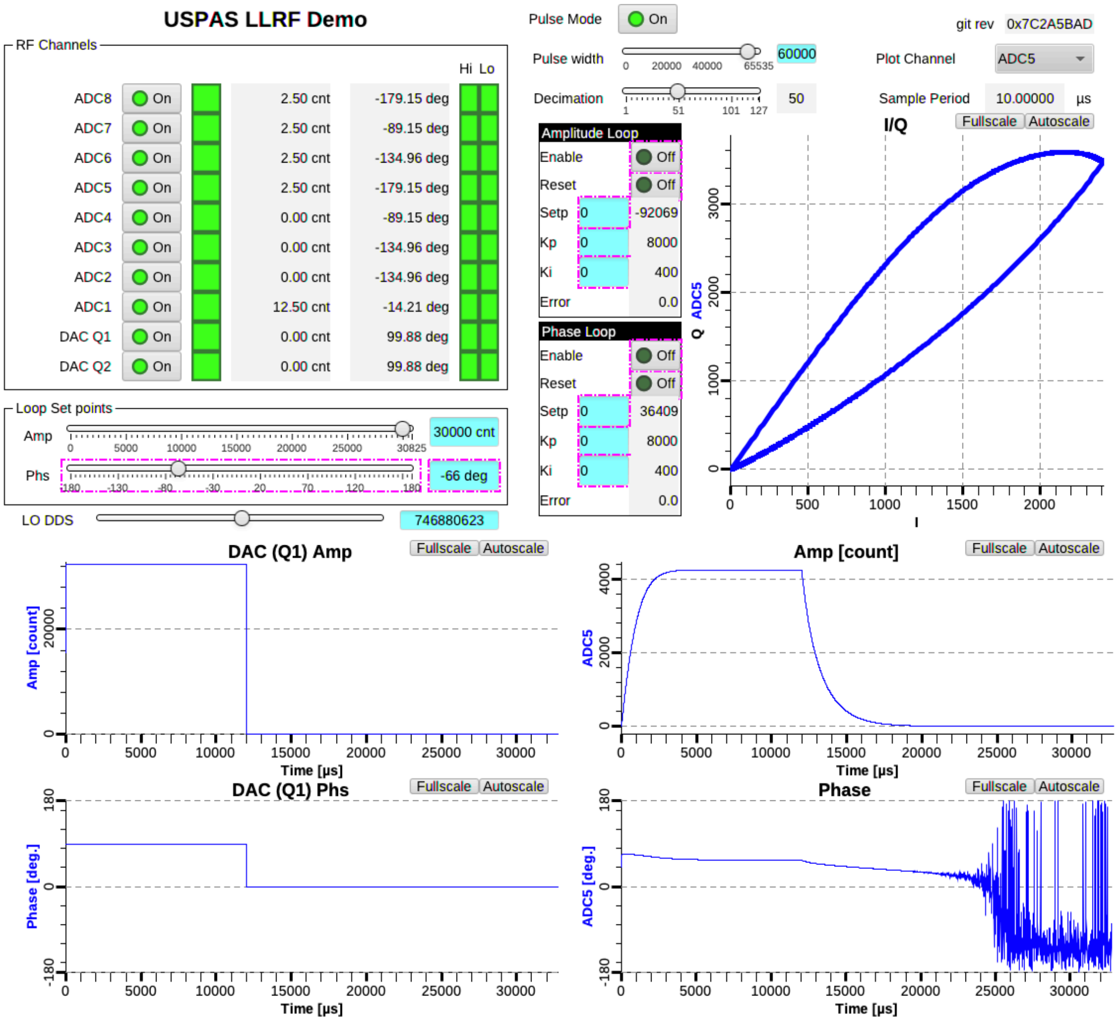
[18]:

```python
new_ph_step = (ph << 12) | pl
```

Adjust DDS frequency!

[19]:

```python
phase_step_pv = PV('USPAS:LLRF:reg_dds_phase_step')
phase_step_pv.value = new_ph_step
```



USPAS LLRF Demo

RF Channels

					Hi	Lo
ADC8	● On	🟩	2.50 cnt	-179.15 deg	🟩	🟩
ADC7	● On	🟩	2.50 cnt	-89.15 deg	🟩	🟩
ADC6	● On	🟩	2.50 cnt	-134.96 deg	🟩	🟩
ADC5	● On	🟩	2.50 cnt	-179.15 deg	🟩	🟩
ADC4	● On	🟩	0.00 cnt	-89.15 deg	🟩	🟩
ADC3	● On	🟩	0.00 cnt	-134.96 deg	🟩	🟩
ADC2	● On	🟩	0.00 cnt	-134.96 deg	🟩	🟩
ADC1	● On	🟩	12.50 cnt	-14.21 deg	🟩	🟩
DAC Q1	● On	🟩	0.00 cnt	99.88 deg	🟩	🟩
DAC Q2	● On	🟩	0.00 cnt	99.88 deg	🟩	🟩

Loop Set points

Amp 30000 cnt

Phs -66 deg

LO DDS 746880623

Pulse Mode ● On

Pulse width 60000

Decimation 50

git rev 0x7C2A5BAD

Plot Channel ADC5

Sample Period 10.00000 µs

Amplitude Loop

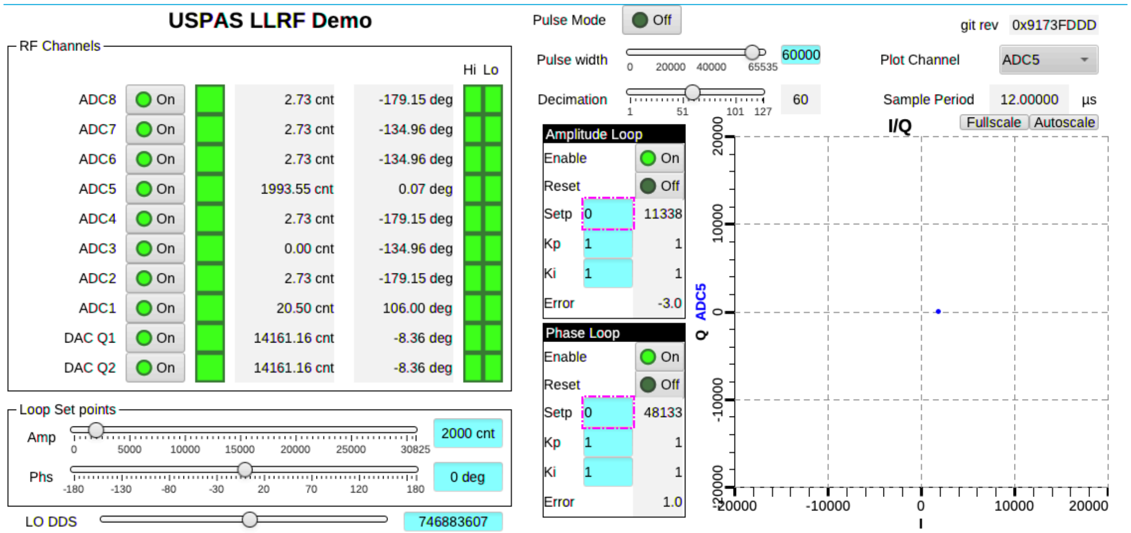
Enable		● Off
Reset		● Off
Setp	0	-92069
Kp	0	8000
Ki	0	400
Error		0.0

Phase Loop

Enable		● Off
Reset		● Off
Setp	0	36409
Kp	0	8000
Ki	0	400
Error		0.0

0.5 Close amplitude and phase loop

1. Disable pulse mode
2. Adjust amplitude setpoint to 2000
3. Set both loops Ki, Kp gain to 1
4. Reset both loops



USPAS LLRF Demo

RF Channels

					Hi	Lo
ADC8	● On	🟩	2.73 cnt	-179.15 deg	🟩	🟩
ADC7	● On	🟩	2.73 cnt	-134.96 deg	🟩	🟩
ADC6	● On	🟩	2.73 cnt	-134.96 deg	🟩	🟩
ADC5	● On	🟩	1993.55 cnt	0.07 deg	🟩	🟩
ADC4	● On	🟩	2.73 cnt	-179.15 deg	🟩	🟩
ADC3	● On	🟩	0.00 cnt	-134.96 deg	🟩	🟩
ADC2	● On	🟩	2.73 cnt	-179.15 deg	🟩	🟩
ADC1	● On	🟩	20.50 cnt	106.00 deg	🟩	🟩
DAC Q1	● On	🟩	14161.16 cnt	-8.36 deg	🟩	🟩
DAC Q2	● On	🟩	14161.16 cnt	-8.36 deg	🟩	🟩

Loop Set points

Amp 2000 cnt

Phs 0 deg

LO DDS 746883607

Pulse Mode ● Off

Pulse width 60000

Decimation 60

git rev 0x9173FDDD

Plot Channel ADC5

Sample Period 12.00000 µs

Amplitude Loop		
Enable		● On
Reset		● Off
Setp	0	11338
Kp	1	1
Ki	1	1
Error		-3.0

Phase Loop		
Enable		● On
Reset		● Off
Setp	0	48133
Kp	1	1
Ki	1	1
Error		1.0

```
[20]: caput('USPAS:LLRF:reg_pulse_mode', 0)
      caput('USPAS:LLRF:Loop:AmpSetp', 2000)
      caput('USPAS:LLRF:reg_Kp_amp', 100)
      caput('USPAS:LLRF:reg_Ki_amp', 1)
      caput('USPAS:LLRF:reg_amp_loop_reset', 1)
      caput('USPAS:LLRF:reg_amp_loop_reset', 0)
      caput('USPAS:LLRF:reg_amp_loop_enable', 1)

      caput('USPAS:LLRF:Loop:PhsSetp', 1)
      caput('USPAS:LLRF:reg_Kp_phs', 100)
      caput('USPAS:LLRF:reg_Ki_phs', 1)
      caput('USPAS:LLRF:reg_phs_loop_reset', 1)
      caput('USPAS:LLRF:reg_phs_loop_reset', 0)
      caput('USPAS:LLRF:reg_phs_loop_enable', 1)
```

```
[20]: 1
```

Increase integral and proportional gain and observe loop stability.