

ACCEL LLRF

Control Algorithm Design

Project: DARPA ACCEL

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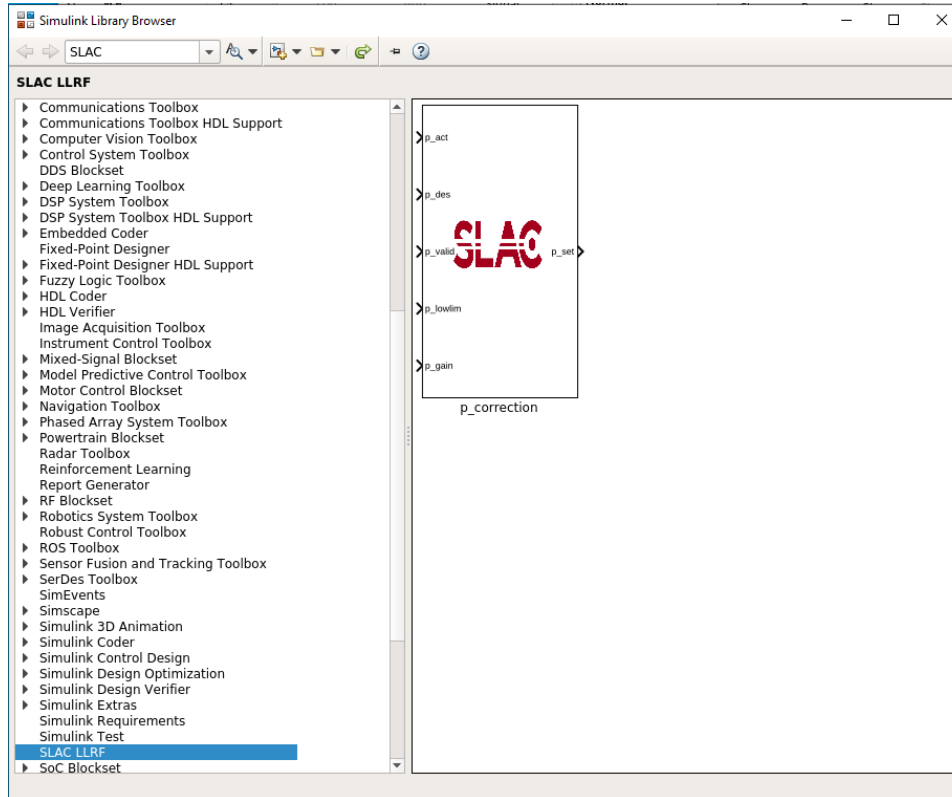
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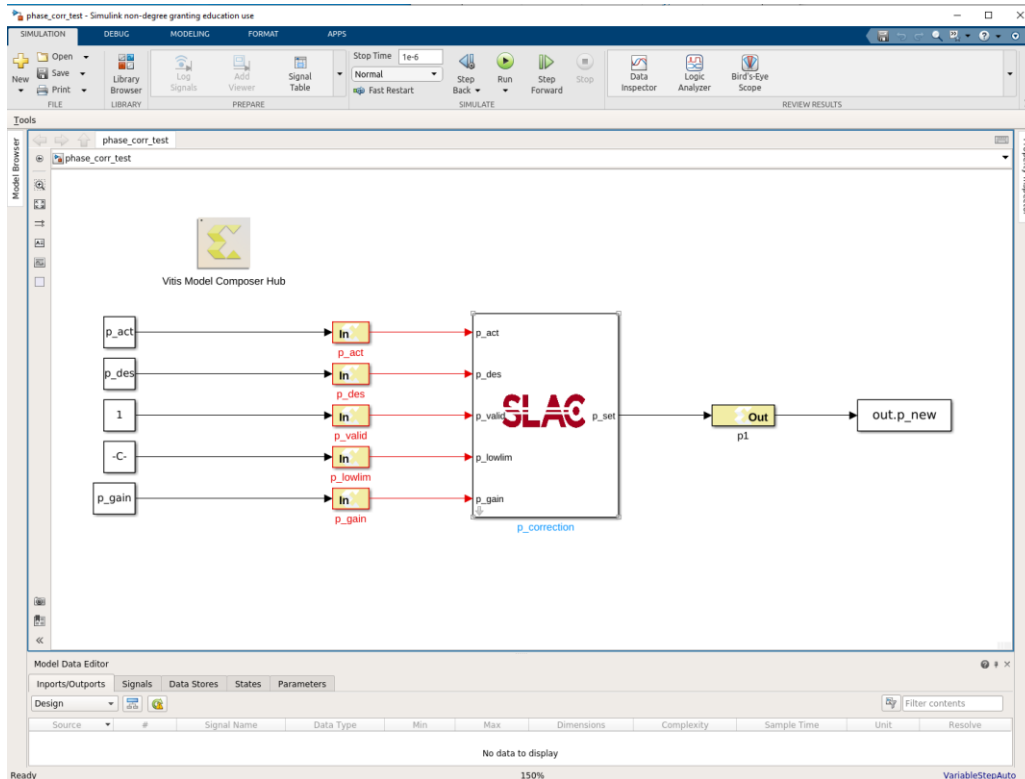
NATIONAL
ACCELERATOR
LABORATORY

Custom Library for SLAC LLRF



- Custom block in Library Browser
- Testbench Simulink model
- Testbench Script
- Phase correction as an example
 - Set the desire phase value
 - Set the lower limit of the phase correction
 - Set the correction gain
 - Get the current phase value
 - Output the new set values for phase

Testbench for Custom Block



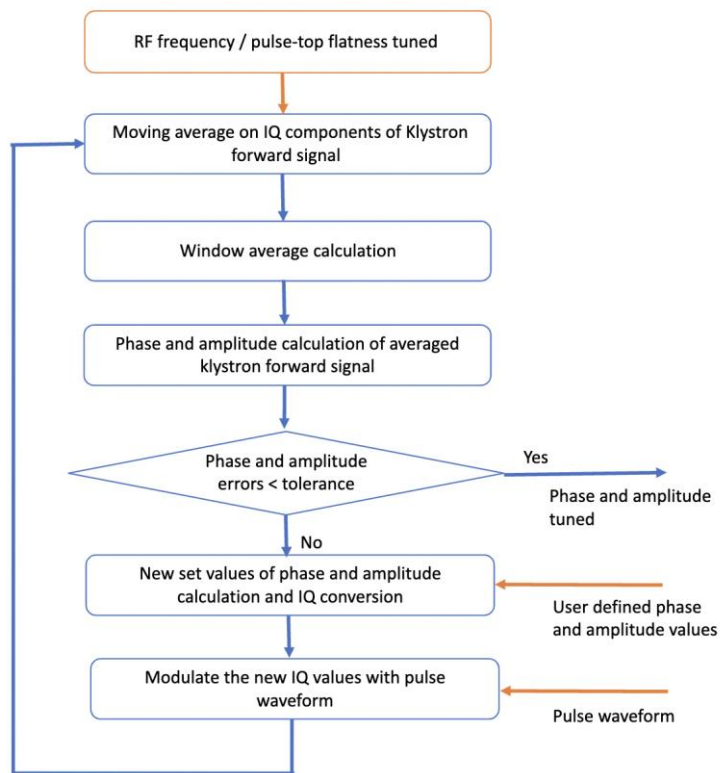
- Custom block
- In and out gateways
 - Output type
 - Arithmetic types
 - Fixed point precision
 - Quantization
- Parameters
 - To and From the workspace
 - Save format

Testbench Script

```
phase_corr_testbench.m x +
1 - clear all;
2 - %% General parameters
3 - fsample=250e6;
4 - period=1/fsample;
5 - runcycle=10;
6 - number_loop=30;
7 - runtime=runcycle*period;
8
9 - %% Custom parameters
10 - p_int=0.1;
11 - p_act=p_int;
12 - p_des=1.5;
13 - p_low_lim=0.1;
14 - p_gain=0.1;
15
16
17 - %% Simulation
18 - figure;
19 - for i=1:number_loop
20 -     %p_act=p_new;
21 -     sim('phase_corr_test.slx', runtime);
22 -     p_new_array=ans.p_new.signals.values;
23 -     p_new=p_new_array(end);
24 -     p_act=p_new;
25 -     plog(i)=p_new;
26 - end
27
28 - plog_i=[p_int,plog]
29
30 - plot(plog_i,'o-'); hold on;
31 - xlabel('Number of Pulses');
32 - ylabel('phase (rad)');
33 - grid on;
```

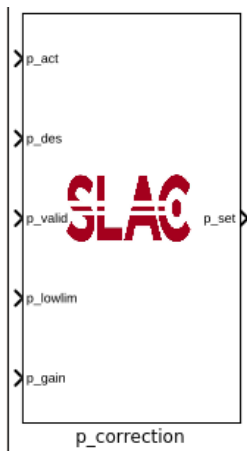
- Setup the general parameters
- Setup the customer parameters
- Call sim to simulate the firmware model
- Use From Workspace to load data to Simulink model
- Use To Workspace to read the output data back to workspace for verification and visualization
 - Plot the results
 - Compare the results for fixed-point to floating point model
 - Verify the function
- Goal: not see Simulink window open

Amplitude and Phase Control



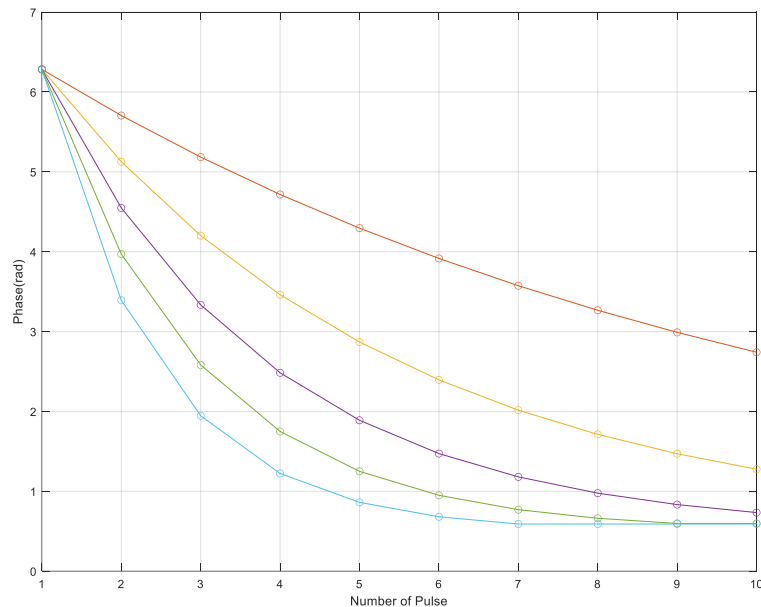
- Amplitude and phase control flow performed after the RF frequency and flatness control
- The phase and amplitude of the klystron forward signal are precisely controlled to user defined values with a real-time compensating loop
- Implementation plan
 - User defined values set in software
 - The target phase and amplitude values set in software
 - User defined waveform corrected by flatness control flow
 - Average values calculated in firmware
 - Streaming IQ samples of the cavity reflection signal are converted to amplitude and phase values in firmware
 - New set of phase and amplitude values calculated based on user defined steps and targets
 - New set values converted back to IQ and then modulated with pulse waveform from software

Phase Control Block

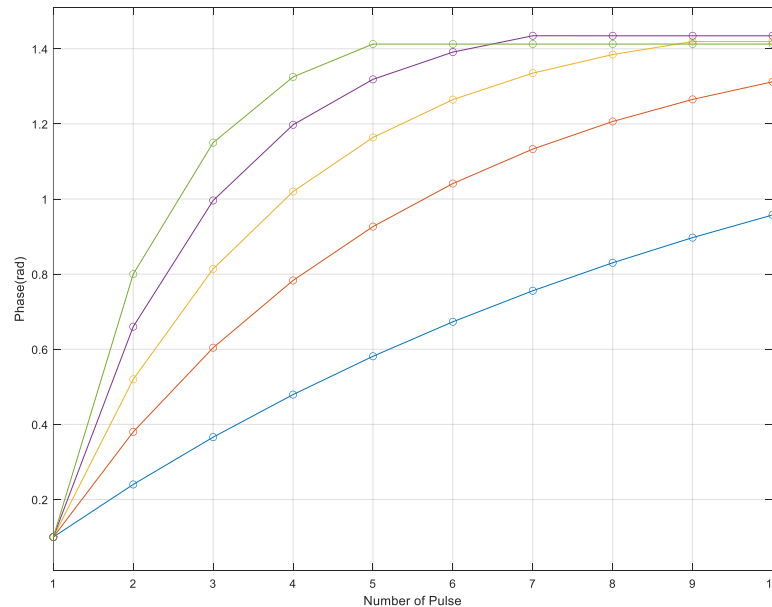


- Take the phase value for each of the pulse
- User defined desired phase value
- Phase correction value calculated
 - Correction value based on the difference between desired value and measurement
 - Correction step controlled by phase control loop gain (user defined)
 - Correction value within lower limit (user defined) - “deadband” the phase no longer changes
- New set value as the output of the block

Phase Control Loop Firmware Simulation Results

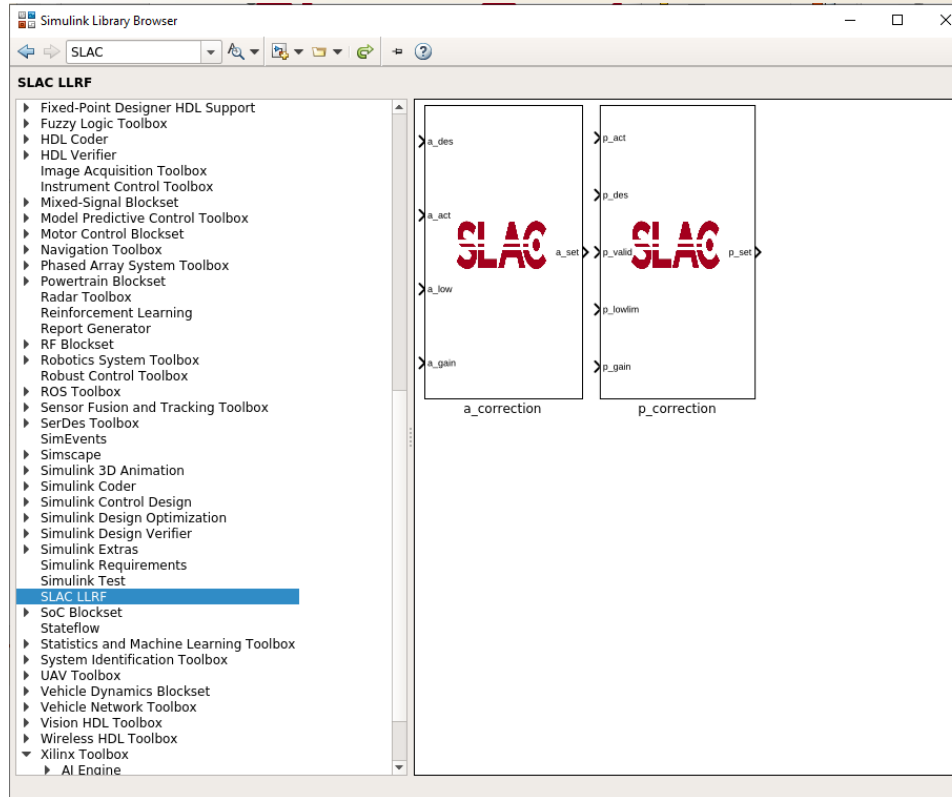


$p_{act} = 2 \cdot \pi$
 $p_{des} = 0.5$
 $p_{gain} = 0.1 - 0.5$



$p_{act} = 0.1$
 $p_{des} = 1.5$
 $p_{gain} = 0.1 - 0.5$

Phase and Amplitude Control Blocks in SLAC LLRF

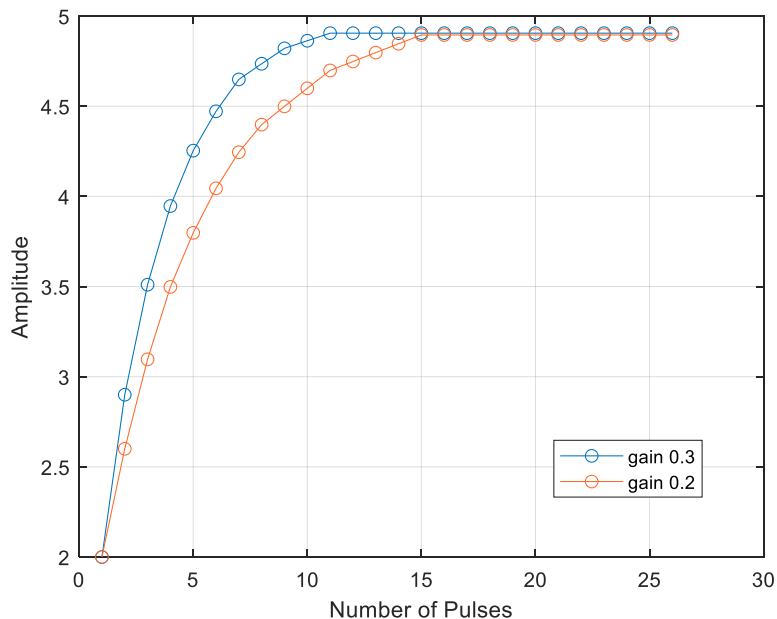


Amplitude Control Block

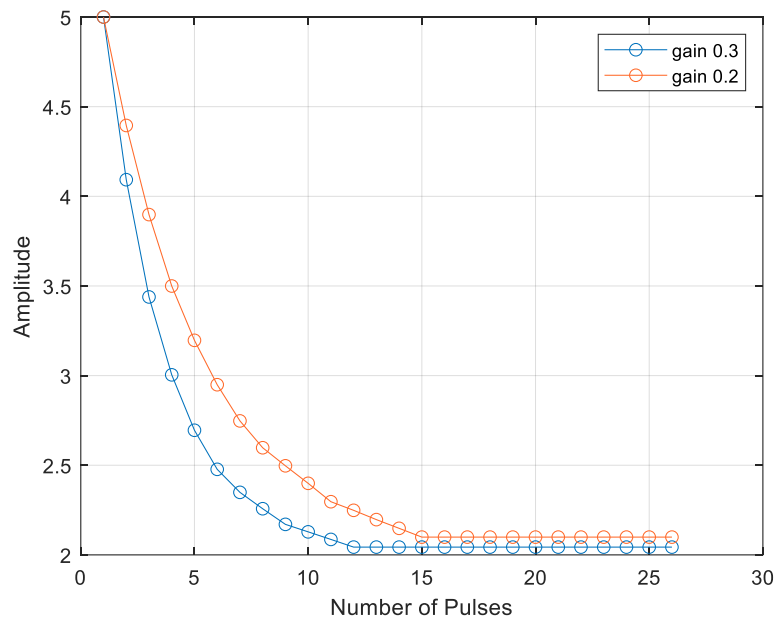


- Take the amplitude value for each of the pulse
- User defined desired phase value
- New amplitude set value calculated
 - Correction value based on the difference between desired value and measurement
$$a_{cor} = \left(\frac{a_{des}}{a_{act}} - 1 \right) \cdot a_{gain} \quad a_{set} = a_{act} \cdot a_{gain}$$
 - Control step controlled by amplitude control loop gain (user defined)
 - Correction value within lower limit (user defined)
 - “deadband” the amplitude no longer changes
- New set value as the output of the block
- Basic function realized, fine tuning and more simulation required for wrapping up the block

Amplitude Control Block



$a_{act} = 2$
 $a_{des} = 5$
 $a_{gain} = 0.2$ and 0.3



$a_{act} = 5$
 $a_{des} = 2$
 $a_{gain} = 0.2$ and 0.3

Thank you!