ACCEL LLRF Control Algorithm Design

Project: DARPA ACCEL

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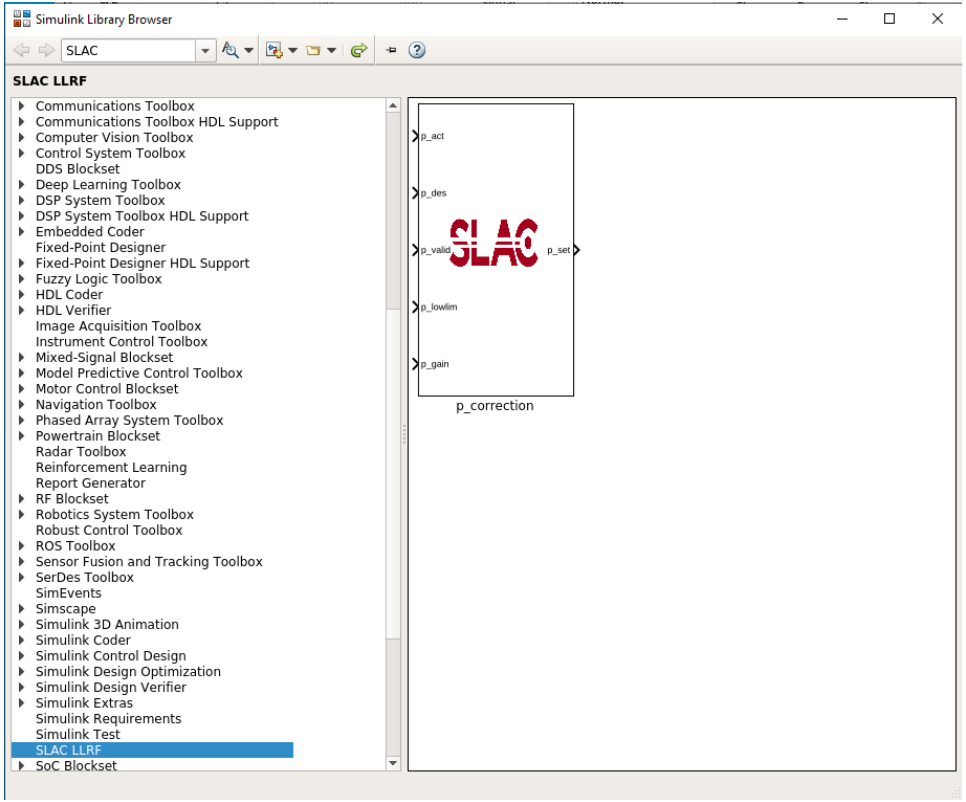
U.S. DEPARTMENT OF ENERGY | Stanford University

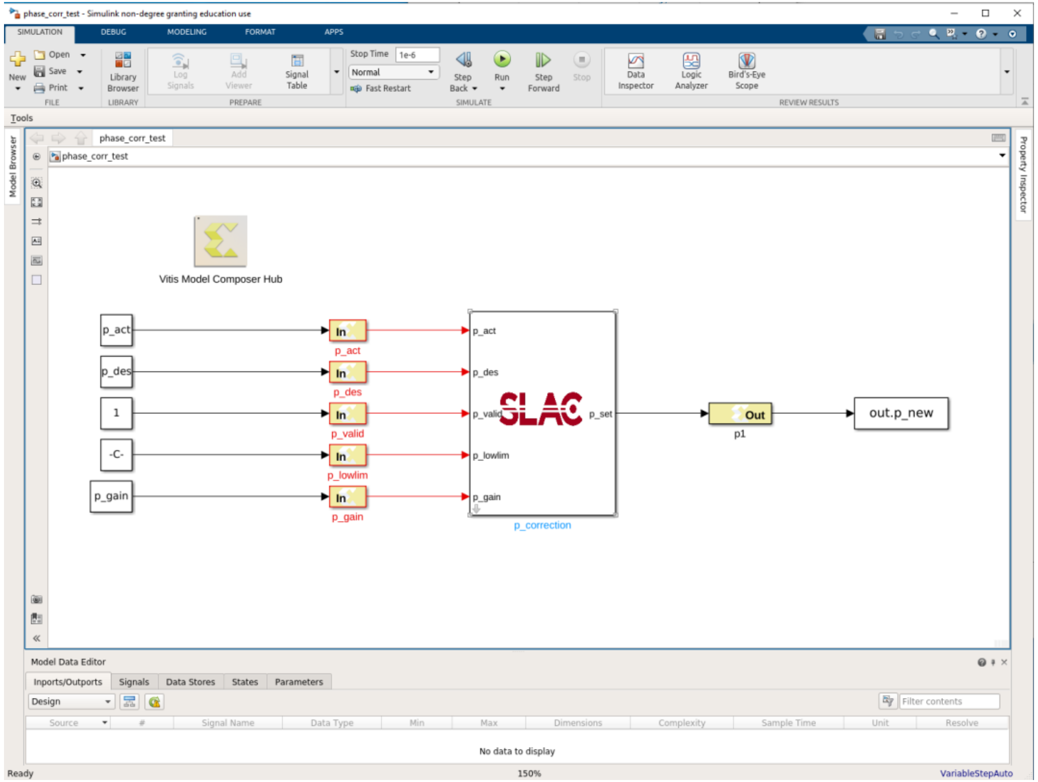
SLAC NATIONAL ACCELERATOR LABORATORY

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

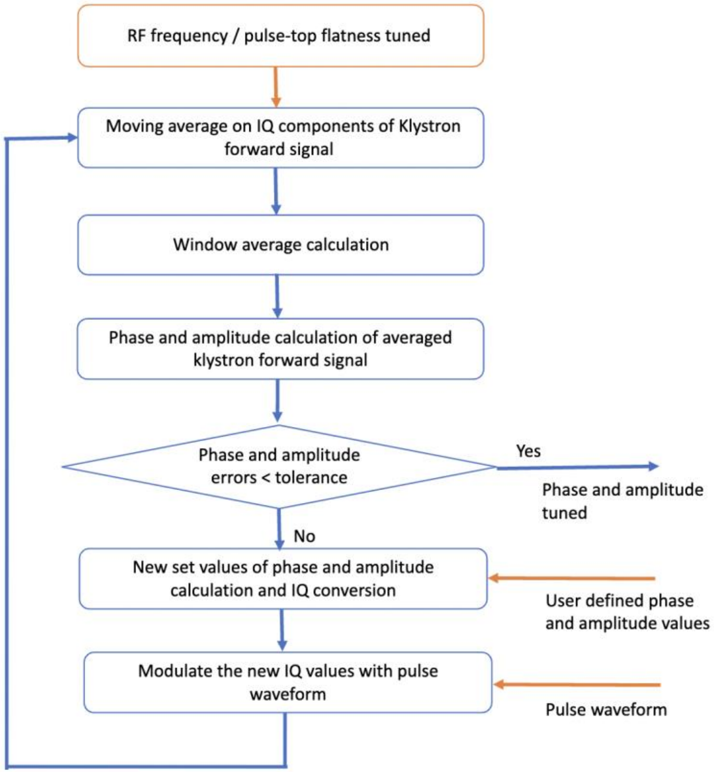
Testbench Script

phase_corr_testbench.m

```
clear all;
%% General parameters
fsample=250e6;
period=1/fsample;
runcycle=10;
number_loop=30;
runtime=runcycle*period;

%% Custom parameters
p_int=0.1;
p_act=p_int;
p_des=1.5;
p_low_lim=0.1;
p_gain=0.1;


%% Simulation
figure;
for i=1:number_loop
%p_act=p_new;
sim('phase_corr_test.slx', runtime);
p_new_array=ans.p_new.signals.values;
p_new=p_new_array(end);
p_act=p_new;
plog(i)=p_new;
end

plog_i=[p_int,plog]

plot(plog_i,'o-'); hold on;
xlabel('Number of Pulses');
ylabel('phase (rad)');
grid on;
```

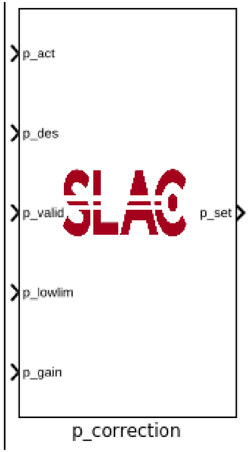
- Setup the general parameters
- Setup the customer parameters
- Call sim to simulate the firmware model
    - Use From Workspace to load data to Simulink model
    - Use To Workspace to read the output data back to workspace for verification and visualization
        - Plot the results
        - Compare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

Amplitude and Phase Control



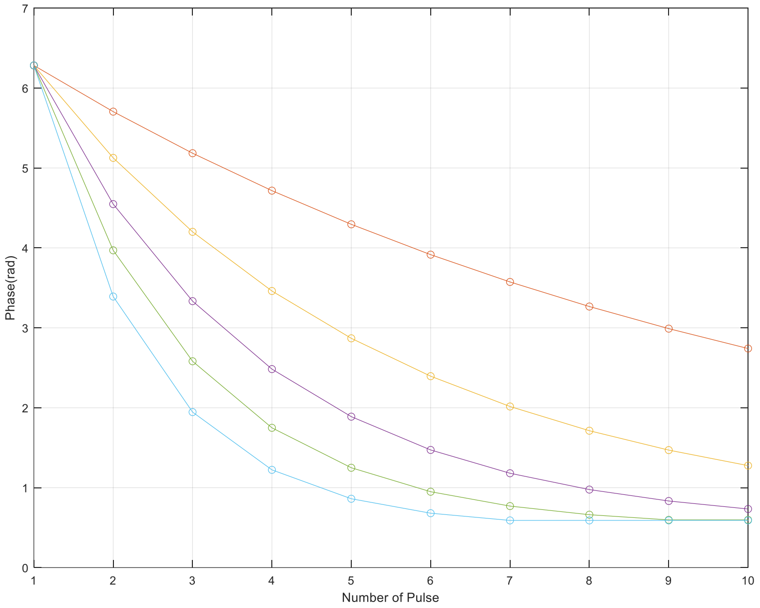
- Amplitude and phase control flow performed after the RF frequency and flatness control
- The phase and amplitude of the klystron forward signal are precisely controlled to user defined values with a real-time compensating loop
- Implementation plan
  - User defined values set in software
    - The 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

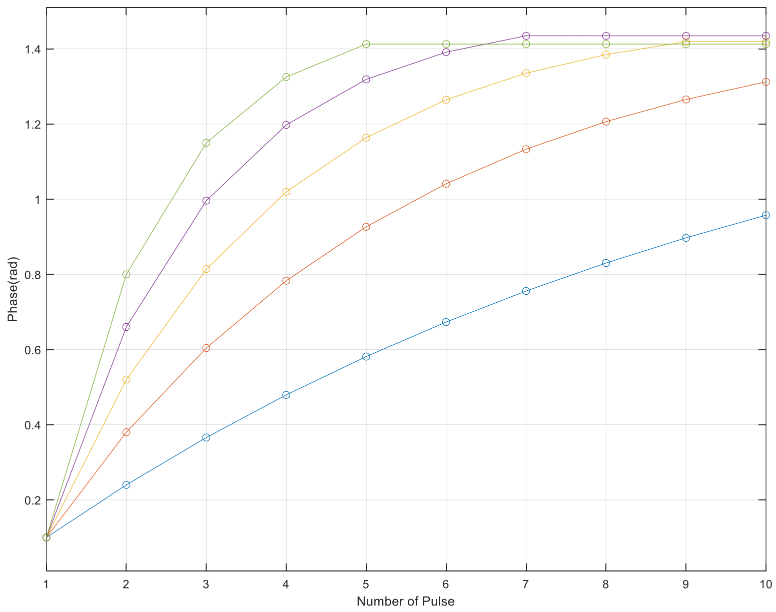
Phase Control Block



- 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

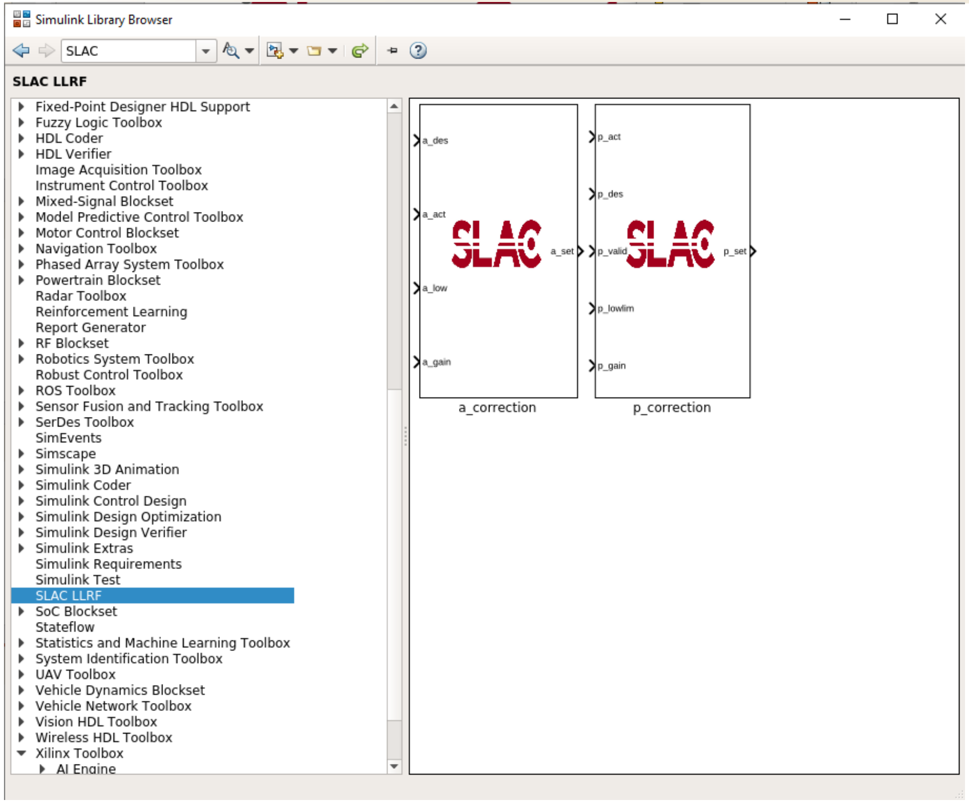




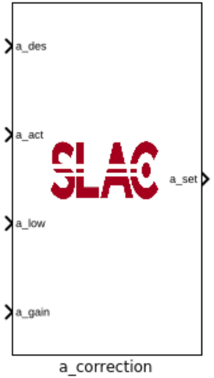
p_act = 2*pi
p_des = 0.5
p_gain = 0.1 - 0.5

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

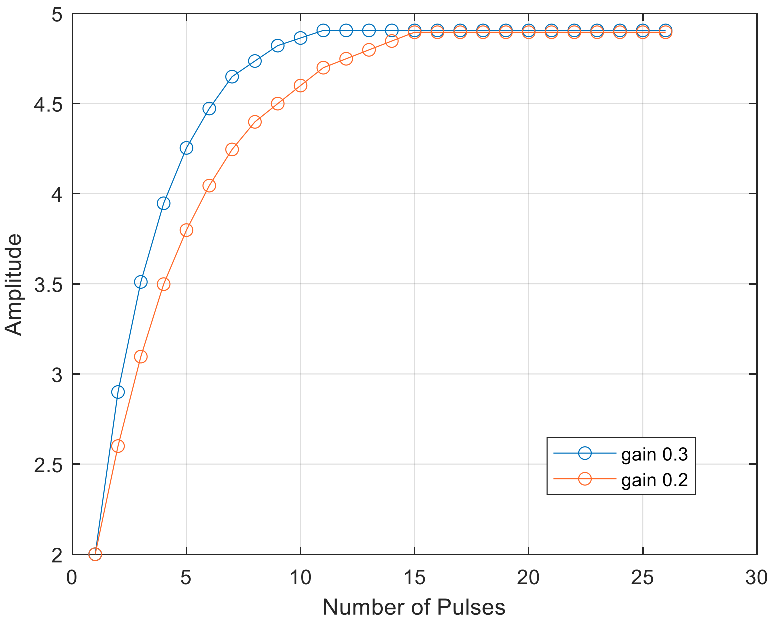


- Take the amplitude value for each of the pulse
- User defined desired amplitude value
- New amplitude set value calculated
  - Correction value based on the difference between desired value and measurement

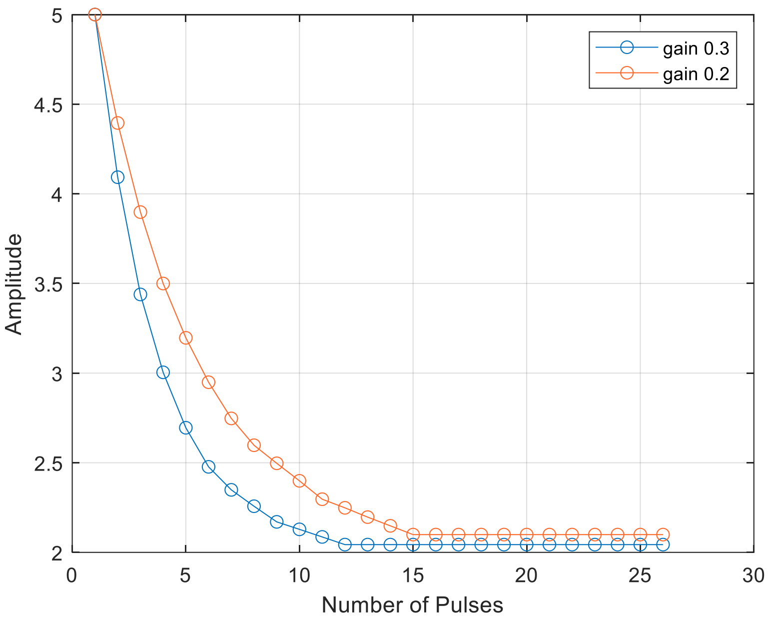
    $$a_{cor} = (\frac{a_{des}}{a_{act}} - 1) \cdot a_{gain} \quad a_{set} = a_{act} \cdot a_{cor}$$

  - 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 tunning 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!