# ACCEL LLRF Control Algorithm Design

Project: DARPA ACCEL

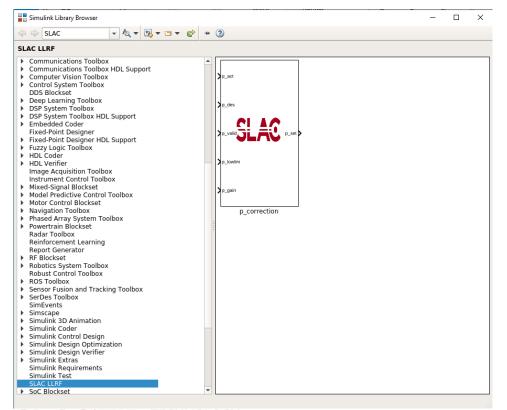
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Date: Feb-Apr 2023





### **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**

| -  |              |   |                                      |                |                          |                 |         |                                      | _    |                |                                 |                 |               |                   |                   |                     | -              |   |           |                     |         |                    |
|--|--------------|---|--------------------------------------|----------------|--------------------------|-----------------|---------|--------------------------------------|------|----------------|---------------------------------|-----------------|---------------|-------------------|-------------------|---------------------|----------------|---|-----------|---------------------|---------|--------------------|
| 瀺 phase, cor_test - Simulink non-degree granting education use 🦳 🗆 🗙 |              |   |                                      |                |                          |                 |         |                                      |      |                |                                 |                 |               |                   |                   |                     |                |   |           |                     |         |                    |
| 5  | IMULAT       | ION   | DEBUG                                | MODELING       | FORMAT                   | 1               | APPS    |                                      |      |                |                                 |                 |               |                   |                   |                     |                |   |           | <ul> <li></li></ul> | ? -     | •                  |
| Ne   | 6            | Open <del>-</del><br>Save -<br>Print -<br>ILE | Library<br>Browser                   | Log<br>Signals | Add<br>Viewer<br>PREPARE | Signal<br>Table | • (     | Stop Time<br>Normal<br>Ref Fast Rest | •    | Step<br>Back • |                                 | Step<br>Forward | Stop          | Data<br>Inspector | Logic<br>Analyzer | Bird's-Eye<br>Scope | REVIEW RESULTS |   |           |                     | -       |                    |
| Tools  |              |   |                                      |                |                          |                 |         |                                      |      |                |                                 |                 |               |                   |                   |                     |                |   |           |                     |         |                    |
| Model Browser  | (ب<br>۲      | ⇔ 🏠<br>™phase_o                               | phase_corr_<br>orr_test              | test           |                          |                 |         |                                      |      |                |                                 |                 |               |                   |                   |                     |                |   |           |                     | -       | Property Inspector |
| Model  | 0 1 H E      |   |                                      |                | $\sim$                   |                 |         |                                      |      |                |                                 |                 |               |                   |                   |                     |                |   |           |                     |         | Inspector          |
|  |              |   |                                      | Vitis Model    | Composer Hi              | ıb              |         |                                      |      |                |                                 |                 |               |                   |                   |                     |                |   |           |                     |         |                    |
|  |              | [   | p_act<br>p_des<br>1<br>-C-<br>p_gain |                |                          |                 | In      | les<br>alid<br>vlim                  |      | ▶ p_           | vali <b>G</b><br>lowlim<br>gain |                 | <b>0</b> p_si | et                |                   | P1                  | )              | → | out.p_nev | v                   |         |                    |
|  | ©<br>₿1<br>≪ |   |                                      |                |                          |                 |         |                                      |      |                |                                 |                 |               |                   |                   |                     |                |   |           |                     |         |                    |
|  | Inpo<br>Desi | el Data Edi<br>orts/Outpor<br>gn<br>Source    | ts Signals                           | œ              | 5 States                 | Paramete        |         |                                      | Min  |                | Max                             | Di              | nensions      |                   | Complexity        | 6                   | ample Time     |   | Filter o  | contents<br>Resolv  | 0 + ×   |                    |
|  |              | source  | • #                                  | Sig            | mai Name                 |                 | ata Typ |                                      | MILL |                | Xlar                            |                 | mensions      |                   | complexity        |                     | ample time     |   |           | ruesolv             | 0       |                    |
|  |              |   |                                      |                |                          |                 |         |                                      |      |                | No data t                       | o display       |               |                   |                   |                     |                |   |           |                     |         |                    |
| Rea  | ady          |   |                                      |                |                          |                 |         |                                      |      |                |                                 | 150%            |               |                   |                   |                     |                |   |           | Variable            | StepAut | 6                  |

Custom block

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

#### **Testbench Script**

SLAC

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

#### 🎭 Custom parameters

- 10 p\_int=0.1;
- 11 p\_act=p\_int;
- 12 p\_des=1.5; 13 - p low lim=G
- 13 p\_low\_lim=0.1; 14 - p\_gain=0.1;
- 14 p\_gain=0.1; 15
- 16 17

9

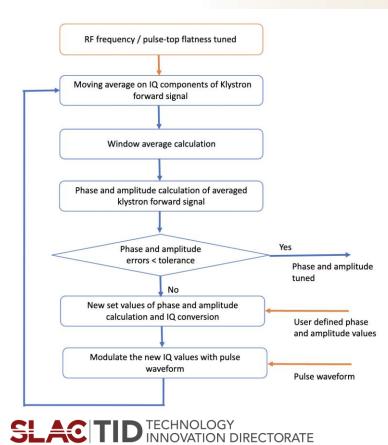
#### Simulation

- 18 <mark>figure;</mark>
- 19 pfor 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;
- 24 p\_act=p\_new; 25 - plog(i)=p\_new;
- 25 plog(1)=p\_new 26 - end
- 20 -
- 28 plog\_i≡[p\_int,plog]
- 29 30 - plot(
- 30 plot(plog\_i,'o-'); hold on; 31 - xlabel('Number of Pulses');
- 32 vlabel('phase (rad)');
- 33 grid on;
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- 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

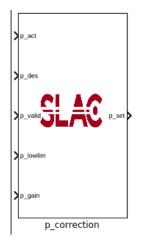
- Compare the results for fixed-point to floating point model
- Verify the function
- Goal: not see Simulink window open

### **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

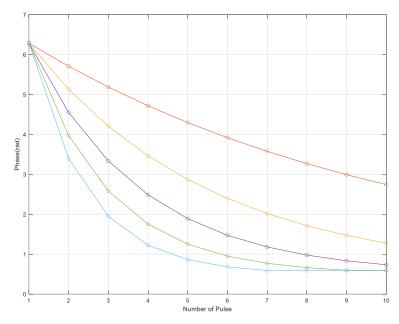
#### **Phase Control Block**



- 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

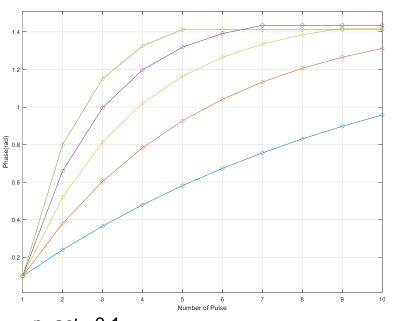


### **Phase Control Loop Firmware Simulation Results**



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





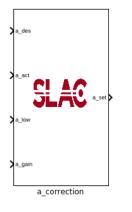
p\_act =0.1 p\_des =1.5 p\_gain = 0.1 - 0.5

## Phase and Amplitude Control Blocks in SLAC LLRF

| 💠 🔿 SLAC 🔍 🗸 🗸   | 🔩 🕶 🐨 🗬 | + (2)   |       |      |
|--|---------|---|-------|------|
| SLAC LLRF  |         |   |       | <br> |
| <ul> <li>Fixed-Point Designer HDL Support</li> <li>Fizzy Logic Toolbox</li> <li>HDL Coder</li> <li>HDL Verifier</li> <li>Image Acquisition Toolbox</li> <li>Instrument Control Toolbox</li> <li>Mixed-Signal Blockset</li> <li>Model Predictive Control Toolbox</li> <li>Motor Control Blockset</li> <li>Navigation Toolbox</li> <li>Phased Array System Toolbox</li> <li>Powertrain Blockset</li> <li>Readar Toolbox</li> <li>Reinforcement Learning<br/>Report Generator</li> <li>RF Blockset</li> <li>Robotics System Toolbox</li> <li>Seroes Toolbox</li> <li>Seroes Toolbox</li> <li>Seroes Toolbox</li> <li>Simulink 20 Animation</li> <li>Simulink Control Toolbox</li> <li>Simulink Control Design</li> <li>Simulink Design Optimization</li> <li>Simulink Design Optimization</li> <li>Simulink Requirements<br/>Simulink Test</li> <li>Soc Blockset</li> <li>Stateflow</li> <li>Statistics and Machine Learning To</li> <li>System Identification Toolbox</li> <li>Vehicle Dynamics Blockset</li> <li>Vehicle Network Toolbox</li> </ul> | _       | A des a_des a_act p_act p_des a_low a_low a_gain a_correction p_gain p_correction | p_set |      |



#### **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

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

- 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**

5 5 <u>000000</u> gain 0.3  $\cap$ gain 0.2 4.5 4.5 4 4 Amplitude 3.5 Amplitude 3.5 3 3 gain 0.3 2.5 2.5 gain 0.2 2 2 10 15 20 25 30 0 5 10 15 20 25 30 0 5 Number of Pulses Number of Pulses  $a_act = 5$  $a_act = 2$ a des = 2a des = 5 $a_{gain} = 0.2 \text{ and } 0.3$ a\_gain = 0.2 and 0.3

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### Thank you!

