ACCEL LLRF Control Algorithm Design

Project: DARPA ACCEL

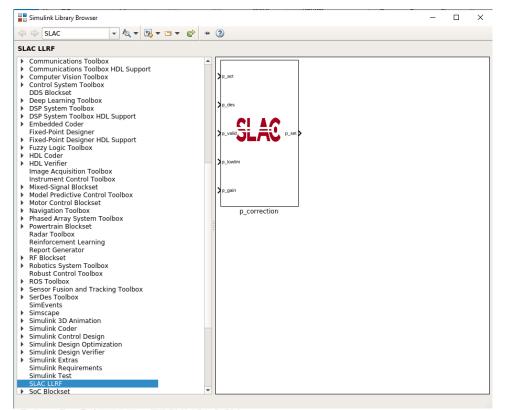
Presenter: Chao Liu

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													 	? -	•
Ne	6	Open - Save - Print - ILE	Library Browser	Log Signals	Add Viewer PREPARE	Signal Table	• (Stop Time Normal Ref Fast Rest	•	Step Back •		Step Forward	Stop	Data Inspector	Logic Analyzer	Bird's-Eye Scope	REVIEW RESULTS				-	
Tools																						
Model Browser	(ب ۲	⇔ 🏠 ™phase_o	phase_corr_ orr_test	test																	-	Property Inspector
Model	0 1 H E				\sim																	Inspector
				Vitis Model	Composer Hi	ıb																
		[p_act p_des 1 -C- p_gain				In	les alid vlim		▶ p_	vali G lowlim gain		0 p_si	et		P1)	→	out.p_nev	v		
	© ₿1 ≪																					
	Inpo Desi	el Data Edi orts/Outpor gn Source	ts Signals	œ	5 States	Paramete			Min		Max	Di	nensions		Complexity	6	ample Time		Filter o	contents 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

•

•

•

- 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

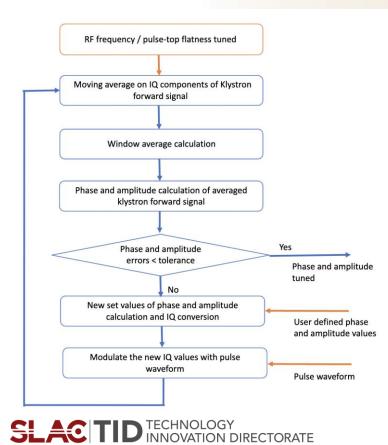
Simulation

- 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;
- SLAC TID TECHNOLOGY INNOVATION DIRECTORATE

- 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

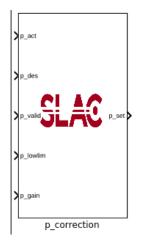
- Compare the results for fixed-point to floating point model
- Verify the function
- Goal: not see Simulink window open

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

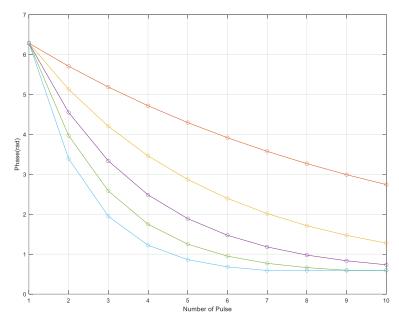
Phase Control Block



- 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

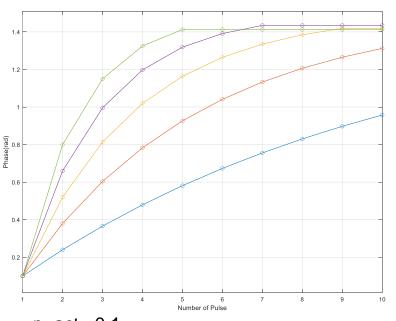


Phase Control Loop Firmware Simulation Results



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





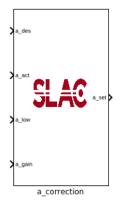
p_act =0.1 p_des =1.5 p_gain = 0.1 - 0.5

Phase and Amplitude Control Blocks in SLAC LLRF

💠 🔿 SLAC 🔍 🗸 🗸	🔩 🕶 🐨 🗬	+ (2)		
SLAC LLRF				
 Fixed-Point Designer HDL Support Fizzy Logic Toolbox HDL Coder HDL Verifier Image Acquisition Toolbox Instrument Control Toolbox Mixed-Signal Blockset Model Predictive Control Toolbox Motor Control Blockset Navigation Toolbox Phased Array System Toolbox Powertrain Blockset Readar Toolbox Reinforcement Learning Report Generator RF Blockset Robotics System Toolbox Seroes Toolbox Seroes Toolbox Seroes Toolbox Simulink 20 Animation Simulink Control Toolbox Simulink Control Design Simulink Design Optimization Simulink Design Optimization Simulink Requirements Simulink Test Soc Blockset Stateflow Statistics and Machine Learning To System Identification Toolbox Vehicle Dynamics Blockset Vehicle Network Toolbox 	_	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 $a_{cor} = (\frac{a_{des}}{a_{act}} - 1) \cdot a_{gain}$ $a_{set} = a_{act} \cdot a_{cor}$
 - 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

SLAC TID TECHNOLOGY INNOVATION DIRECTORATE



Thank you!

