## **SNS LLRF Design Experience and its Possible Adoption for the ILC**

### Brian Chase SNS - Mark Champion



International Linear Collider Workshop

11/28/2005

## Why Consider the SNS System for ILC R&D at SMTF

- Close to state of the art components (2 yrs old)
- System is operational and meeting SNS specs
- The design team is fresh from the current design and can easily modify for 1300 MHz
- The Epics interface is complete and there is state control for startup and exception handling
- Lots of commonality with FNAL LLRF systems, Such as VXI and VxWorks OS running on PPC

#### Each Rack in the Superconducting Linac Contains LLRF Hardware for Two RF Systems





Typical LLRF control rack installation in the superconducting linac.

The VXI crate contains:

- Input/Output Controller: PowerPC running VxWorks
- Utility Module: Decodes events from Real Time Data Link
- Timing Module: Generates RF Gate timing signal
- Two FCM/HPM pairs



# The Field Control Module (FCM) consists of a motherboard and three daughterboards







#### **Block Diagram of the SNS Linac LLRF Control System**



July 28, 2005

PALLADION NO.



# Advanced FeedForward techniques are being developed to maximize performance

- Cavity fill is best achieved using feedforward techniques.
- Feedback control is reserved for maintaining the cavity field after the desired operating point has been reached.
  - Allows for higher gain settings and tighter regulation
- In this example, the incident RF power is highest during the cavity fill so that the target field can be achieved within a fill time of 300 us.
- The phase push is being compensated by a ~20 deg/ms compensatory slope on the feedforward curve.







- Auto-Run sequencer ramps up cavity field under open-loop conditions.
- Auto-Tune sequencer maintains correct cavity frequency.
- Upon reaching the desired gradient, the feedback control loop is engaged.
- In this example, all available cavities (19) for cryomodules 1-8 were turned on automatically.

LLRF Operator Screens: SC Linac 01a-08c																				
	Status	Ampl. Setpt.	Gradient [MV/m]	Power [k₩]	Phase Stpt.[deg	Phase ] [deg]	Reson. Err.[kHz]	Width [usec]	Rep. Rate	Clse Loop	d. Auto ? -Run	IOC Load	Vac C Coupl	ryo Transmit er State	tter	Modulator State	Modulator [kV]	HPRF Tir Wid. [us	ning ec], Rate	
01	a	5.000	5.07	20.12	-136.4	9.2	0.08	1270	10 Hz		Closed	28 %		Rdy.	For HV	Rack Run	69.0	1550	10 Hz	<b>.</b>
01	b 📃	5.000	5.02	14.05	-25.9	-37.9	-0.02	1270	10 Hz		Closed									-
01	c 📘	5.000	4.91	23.53	117.7	86.1	0.04	1300	10 Hz		Closed	28 %								
02	a	5.000	4.93	23.53	0.0	-0.8	0.05	1270	10 Hz		Closed									ArcTes
02	b	5.000	5.00	26.47	0.0	-0.8	0.05	1270	10 Hz		Closed	27 %								
02	c 📘	5.000	5.03	25.84	0.0	-0.7	0.09	1270	10 Hz		Closed			<u> </u>	•					
03	a	5.000	5.00	18.50	1.0	-0.9	-0.01	1300	10 Hz		Closed	27 %		Rdy.	For HV					
03	b	5.000	4.90	17.16	0.0	0.4	0.04	1300	10 Hz		Closed				1					
03	с <mark>с</mark>	5.000	5.01	17.46	-43.6	-0.8	0.01	1270	10 Hz		Closed	27 %								
04	a	5.000	5.01	19.71	-9.1	-1.1	0.03	1270	10 Hz		Closed	00.0								Arcles
04	b d	0.000	0.03	0.01	3.0	-27.6	0.00	1270	10 Hz		Off	26 %								
04		2.950	5.05	19.84	-38.4	-38.0	0.08	1270	10 Hz		Closed	26.94				De els D	<u> </u>	1550	10 11	<b></b>
05		1.950	5.17	18.33	0.0	-7.7	0.00	1270	10 Hz		Off	20 %		Rdy.	ror HV	Rack Run	69.0	1550	IU Hz	
05		0.000	5.10	16.54	-00.0	137.9	0.00	1270	10 HZ	=	OFF	26.9/								
05		5.000	4 99	18 93	-18.2	- / 1.6	0.00	1270	10 HZ		Closed	20 %		·····						ArcTes
00		5.000	4 98	13 89	-114.5	123 7	-0.00	1270	10 Hz		Closed	27 %		· · · · · · · · · · · · · · · · · · ·						
00		5.000	5.01	21.24	7.3	66.6	0.03	1270	10 Hz	Ξ	Closed									
07		9.850	10.11	65.77	-85.5	20.6	-0.01	1270	10 Hz		Closed	29 %		Rdv.	For HV					
07		7.079	.07	29.72	0.0	133.5	0.01	1270	10 Hz		Off									
07	۰ <mark>ا</mark>	5.000	5.02	16.87	-120.0	31.9	-0.01	1270	10 Hz		Closed	26 %								
08	a 📕	5.000	5.05	13.93	0.2	41.0	0.03	1270	10 Hz		Closed									ArcTes
08	b	5.000	4.96	15.58	3.0	-1.7	-0.07	1270	10 Hz		Closed	28 %								
08	c 🗌	5.000	4.97	13.71	0.0	-1.9	0.02	1270	10 Hz		Closed									
:				Amplitudes		S	CL 04c LLF	٩F						06/15/0	05 19:17:29	Detail				
		600		Amplitudes	_	A	nplitude	Mismato	:h w/ Aut	o-Rur	ngoal Auto- Bun	Stat	tus		Lim	its, Faults				
		400				0		5.10	0		25 5.00	0 Seq	uencer	Operation	🔵 Res	Err. 👝				
		300			- M	Ca	av. [MV]	Fwd. [k	W] Re	efl. (k'	W] SV F	Fred	q. Offs.	0.00 kHz	Pov	/er 🦲				
		200			<del>~</del> \	PI	o.uo hase	-	9.8		10.3	RE F	Rate		Dut	y Cyc. 🦲				
		100				-20	00	-36			200				SI	atus				
			0 <del>1 i i i i i i i i</del> i i i i i i i i i i i	0 600 80 ( 100)	ריי <del>ן ילין י</del> 120140160		-38.0	- 2	8.0	- 11	32 3	\	Width	[1270.0 uS		PM 😑				
				u pr						1.		RF	Load	0.047 kW	C	natter Ceg	end Ded best	Quartit		
		_ ra		<u> </u>	15/05 18:38	:43 Closed	Loop									Am Pha	pl. Setpoint: Re ase Setpoint: Re	d '!!' = Differ d '!!' = Phas	s. s from auto- se shifted.	run goal.



ORNL

7

# The Cavity Tuning System has been tested and is ready to support the SCL beam commissioning run



The LLRF Control System calculates the resonance error based on the cavity field decay.

The Cavity Tuning System drives the stepper motor inside the cryomodule to tune the cavity.

Manual and Automatic modes of operation have been tested.

In Automatic mode, the cavity frequency is maintained within a configurable deadband (+/- 100 Hz typical).



#### **Transient Response of Feedback Control on DTL1**

(Courtesy of H. Ma)



July 28, 2005



### Droop on the SCL klystron high-voltage pulse induces phase push of ~50 deg (worst case)

→ LLRF must compensate this effect



ORNL

#### Implementation of a Gain Rotation Ramp provides for Compensation of the Phase Push



July 28, 2005



#### Adaptive FeedForward Beam Compensation was Deployed during SNS NC Linac Commissioning



Fig. 1 Beam loading in DTL6 with ~40 us, 20 mA beam induced error of 2.7% and 2 deg in amplitude and phase.



Fig. 2 Beam loading eliminated by means of Adaptive FeedForward.



SPALLATION NEUT

# **SNS Design Experience**

- The first design effort failed schedule requirements and the project was restructured late in the game. There are many reasons why this project got into trouble.
- Recommendations for ILC
  - Treat LLRF as a core competency, not a commodity!
  - On site team must have project control
  - Build and plan to keep a strong team on site as they will be key to many modifications and upgrades over the life of the machine



### **RF Parameters**

Parameter/ System	Main Linac	Bunch Compressor	SNS Linac		
<b>Uncorrelated Amplitude</b>	0.5%, 0.5 deg	0.08%, 0.03 deg	0.3%, 0.3 deg		
Correlated	0.03%, 0.1 deg	0.03%, 0.03 deg			
<b>Bunch to Bunch Energy</b>	0.05%				
Stored Energy W	144J/m				
Gradient	35MV/m				
Beam Current	9.5mA				
Uncorrelated / Klystron	0.5%				
Klystrons/Linac	286				
Cavities/Klystron	24 or 36				
Loaded Q	<b>2.6E6</b>				



International Linear Collider Workshop

### **SNS LLRF at FNAL**

- FNAL will supply a VXI crate and a slot 0 controller to SNS
- SNS is ordering the needed RF and IF filters
- Multi-cavities can be supported with an analog vector sum of the 50 MHz IF signals now, with an FNAL 36 channel 12 bit 65 MHz ADC module in the future
- Hopefully we will have two operational LLRF systems to compare and contrast!



# **ILC LLRF Design Cycle**

- LLRF is based on computer and communication technology and has been following Moore's law. Eight years = 2^5
- Design algorithms and topologies now and repeat prototype hardware design cycle every 2.5 years. Production at 18 months before commissioning
- Continued R&D at test and operational facilities



### Structure of an LLRF Collaboration for the ILC

- There are many labs worldwide that have experienced LLRF teams that could contribute to the ILC.
- These teams could be productively involved in the specifications, design, production of hardware, firmware and software.
- Parallel design paths for several years of R&D
- 1% luminosity at the ILC is worth many \$ millions
  - There are many ways to optimize performance with control systems - LLRF is a key controller for the ILC and should be highly optimized!



## Conclusions

- SNS LLRF can meet the present needs for ILC R&D at FNAL SMTF and the SNS team is very interested in being involved
- Parallel design efforts are a good thing at this point in the project
  - We would benefit from a common IF frequency (52.00 MHz?)
  - Beam instrumentation might use the same IF?
- High performance electronic system designs such as LLRF, instrumentation and controls should not be frozen like the basic machine design. They need to stay "just in time" and continue to evolve with new technologies.

