Reduced bunch operation in DRFS

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BAW-2 Schedule

- **Tuesday18.01 Reduced bunch number operation (day #1)**
- 11:00-12:30 HLRF considerations (KCS/RDR and DRFS)
  - Consider only 500 GeV operation (i.e. maximum gradient operation at 5Hz rep. rate).
  - Klystron/modulator counts, including reevaluation of overhead for gradient spread (at lower current)
  - Cost estimation of unit hardware (reduced factor mass-production)
  - Options and support for recovery scenarios (i.e. restoring full RDR 9mA current).

  Note that it is currently assumed that KCS/RDR will consider a 6 mA (1.6ms) scenario, while DRFS will use 4.5 mA (2.2ms).
- **Thursday 20.01 Relocation of positron source (day #1)**
- 11:00-12:00 HLRF 10Hz operation considerations (KCS/RDR and DRFS)
  - Consider for reduced nb scenario only.
  - Implication of 10Hz operation at reduced linac average gradient
  - RF power source efficiency
  - Additional requirements for 10Hz operation

Start Point for DRFS Scheme

- It is necessary to clear the ILC Construction/Operation Schedule for DRFS since HLRF hardware in the tunnel has to be upgraded.
- Consistent model and scheme is inevitable for all over the periods of ILC schedule in DRFS.
  - Start from Low Energy 10 Hz Option and Establish RF Scheme and Layout which enable us to realize Low Energy 10 Hz Option. Then, this scheme is extended to Low Power Option.
  - This model presents consistent and valid scheme for the period from Low Energy 10 Hz Option to Full ILC including Upgrade.
- Consistent cost evaluation and heat dissipation will be achieved.

ILC Construction/Operation Scheme and DRFS

Schedule scheme presented at AD&I meeting in Dec. 8 (Wrong understanding?)

Step	Status	Mode	Energy(GeV)	Current(mA)	Rep. Rate (Hz)	Rel. Beam Power
0 ? 0-0	Operation Upgrade	Low Energy Option	250	4.5	5	0.25
0-1	Operation	Low Energy Option 10 Hz	250	4.5	10	0.5
		Revised from 10Hz Operation Mode to SB2009				
0-2 0-3…… 1-0	Operation ↓ Upgarde	300 GeV Operation ↓	300	4.5	5	0.3
1-1	Operation	Low Power Option SB2009	500	4.5	5	0.5
2-0	Upgrade	4000 RF Sources are installed				
2-1	Operation	RDR	500	9	5	1

Wrong understanding?)

ILC Construction/Operation Scheme and DRFS (revised)

Revised schedule scheme and base of the presentation for BAW-2 achieving the high efficiency operation of klystron in lower voltage.

Step	Status	Mode	Center of Mass Energy	Current	Electron		Pos		Beam
					Energy	Rep			
			(GeV)	(mA)	(GeV)	(Hz)			
0?	Operation	Low Energy Option	250	4.5	125				0.25
0-0	Upgrade								
0-1	Operation	Low Energy Option 10 Hz	250			5	125	5	
							ation Mode to SB2009		
0-2	Operation	300GeV			150	5	150	5	.3
0-3									
1-0	Up								
1-1		SB2009	500	4.5	250	5	250	5	0.5
2-0				4000 RF Source are installed					
2-1		RDR	500	9	250	5	250	5	1

Frequent energy change from Low-energy 10Hz to 300-350 GeV Operation might be expected and interruption of hardware change is not welcomed.

ILC Construction/Operation Scheme and DRFS (new version for BAW2)

New version of DRFS applicable to SB2009 and low energy 10 Hz operation is presented in BAW2. In new version, basically there is no period to change the HLRF hardware from 10 Hz operation to another higher energy 5 Hz operation.

DRFS can easily changes the number of active klystrons to accelerate beams to the different energy. Still certain modification is necessary from SB2009 to full ILC specification.

Step	Status	Mode	Center of Mass Energy	Current	Electron		Positron		Rel. Beam Power
					Energy	Rep	Energy	Rep	
			(GeV)	(mA)	(GeV)	(Hz)	(GeV)	(Hz)	
0? 0-0	Operation Upgrade	Low Energy Option	250	4.5	125	5	125	5	0.25
0-1	Operation	Low Energy Option 10 Hz	250	4.5	150 125	5 5	125	5	<0.5
0-2 0-3	Operation	300GeV Operation ⇩	300	4.5	150	5	150	5	0.3
1-1	Operation	Low Energy Option SB2009	500	4.5	250	5	250	5	0.5
2-0	Upgrade	4000 RF Source are installed							
2-1	Operation	RDR	500	9	250	5	250	5	1

Important issues for half current option in DRFS

- In half current option of 4.5mA, due to the Q_L change, filling time is longer than full current case of 9mA (t_r=0.6-0.7 -> 1.1ms) .
- From the sc cavity manufacturing, field gradient variation of 31.5MV/m+-20% is required to be accepted. For the cavity of higher gradient, more longer filling time is required and effects for the design of power supply are important.
- In the DRFS, varied cavities are sorted into the five bins, and the cavities of almost the same quality are installed in the DRFS system of each power supply group.

Sorting Bin For Cavity 32.8MV/m+-20% Critical Coupling I=4.5mA

Sorting Bin	Sorting Range	Lowest of Bin(%)	Max Grad. of Bin	Min. Grad.of Bin	Min. Acc. Gain	Fraction	Coupling	Pulse width	Po/Cav.	4*Po	4* Po with 20% overhead
	%	%	MV/m	MV/m	MV	%		ms	kW	kW	MW
A	120-112	112	39.4	36.8	38.14	20	Matching	2.30	162.93	651.72	814.65
B	112-104	104	36.8	34.1	35.41	20	Matching	2.25	153.67	614.68	768.35
C	104-96	96	34.1	31.5	32.96	20	Matching	2.18	141.92	567.68	709.60
D	96-88	88	31.5	28.9	29.96	20	Matching	2.11	130.63	522.52	653.15
E	88-80	80	28.9	26.3	27.27	20	Matching	2.03	119.81	479.24	599.05
Average		96	34.14	31.52	32.75			2.17	141.79	567.17	708.96

Power of A-bin exceeds 800 kW and maybe 850kW might be desirable to accept for 31.5MV/m+-20%. Condition of full energy version is more severe for RF operation.

Accepting 31.5MV/m+-20% and Full Energy Operation

Sorting Bin For Cavity 32.8MV/m+-20 Critical Coupling I=9mA

Sorting Bin	Sorting Range	Lowest of Bin(%)	Min. Grad.of Bin	Min. Acc. Gain	Fraction	Coupling	Pulse width	Po/Cav.	2*Po	Overhead	4* Po with 20% overhead
	%	%	MV/m	MV	%		ms	kW	kW	%	MW
A	120-112	112	36.8	38.14	20	Matching	1.80	368.77	737.54	20.0	921.925
B	112-104	104	34.1	35.41	20	Matching	1.76	349.53	699.06	20.0	873.825
C	104-96	96	31.5	32.96	20	Matching	1.71	332.7	665.4	20.0	831.75
D	96-88	88	28.9	29.96	20	Matching	1.66	313.19	626.38	20.0	782.975
E	88-80	80	26.3	27.27	20	Matching	1.61	296.38	592.76	20.0	740.95
Average		96	31.52	32.75			1.71	332.11	664.23		830.29

20 % of LLRF overhead is not allowed for the current DRFS specification. Over-coupling doesn't give any benefit for HLRF.

Sorting Bin For Cavity 32.8MV/m+-20 Critical Coupling I=9mA

Sorting Bin	Sorting Range	Lowest of Bin(%)	Min. Grad.of Bin	Min. Acc. Gain	Fraction	Coupling	Pulse width	Po/Cav.	2*Po	Overhead	2* Po with 20% overhead
	%	%	MV/m	MV	%		ms	kW	kW	%	MW
A	120-112	112	36.8	38.14	20	Matching	1.80	368.77	737.54	7.9	800.8
B	112-104	104	34.1	35.41	20	Matching	1.76	349.53	699.06	13.7	800.8
C	104-96	96	31.5	32.96	20	Matching	1.71	332.7	665.4	17.9	800.7
D	96-88	88	28.9	29.96	20	Matching	1.66	313.19	626.38	20.0	783.0
E	88-80	80	26.3	27.27	20	Matching	1.61	296.38	592.76	20.0	741.0
Average		96	31.52	32.75			1.71	332.11	664.23		785.24

Reducing overhead to 7.9% scarifies the beam feed-back operation.

Likely level of output power

Sorting Bin For Cavity 32.8MV/m+-20 Critical Coupling I=9mA

Sorting Bin	Sorting Range	Lowest of Bin(%)	Min. Grad.of Bin	Min. Acc. Gain	Fraction	Coupling	Pulse width	Po/Cav.	2*Po	Overhead	2* Po with 20% overhead
	%	%	MV/m	MV	%		ms	kW	kW	%	MW
A	120-112	112	36.8	38.14	20	Matching	1.80	368.77	737.54	13.3	850.7
B	112-104	104	34.1	35.41	20	Matching	1.76	349.53	699.06	17.8	850.4
C	104-96	96	31.5	32.96	20	Matching	1.71	332.7	665.4	20.0	831.8
D	96-88	88	28.9	29.96	20	Matching	1.66	313.19	626.38	20.0	783.0
E	88-80	80	26.3	27.27	20	Matching	1.61	296.38	592.76	20.0	741.0
Average		96	31.52	32.75			1.71	332.11	664.23		811.36

Effect of change specification of HLRF by reducing the current in half (SB2009).

- In SB2009 (half current option), optimistic model proposed in AD&I webex meeting of Dec.21,2010 was not valid after the detailed calculation (Model which combined with longer pulse operation and over-coupling operation). Even for the large over-coupling, tr is not reduced to 1.65ms while required power increase largely.
- In low energy 10Hz operation, DRFS proposal to adopt the high-efficiency klystron operation at the lower output power of 400kW was also revised corresponding to the request to eliminate hard-ware modification period. This point is explained in presentation of 20 Jan. 2011 in BAW-2.
- In this workshop, revised model which is applicable to half-current option and low energy 10Hz operation will be presented. It is necessary to clear the HLRF specification satisfying the reduced bunch operation and the acceptance of cavity gradient variation.

Results of DRFS scheme come from low energy 10 Hz operation

- From the DRFS design considering of low energy 10 Hz operation, very likely plan is almost the same configuration as SB2009. About half of klystrons connecting to 4 cavities are operated at full output power level of 800kW. If all power supplies have the capability of producing longer pulse of 2.3ms, maximum repetition of 10 Hz are available in low energy 10 Hz operation. Detail is presented in 20 January, 2011.
- Conclusion of the design is summarized in the bottom table.
- This scheme is valid for electron linac only, but positron linac employs the same manner since it must also accept the cavity sorting of cavity variation.

ALL DC Power Supply & Mod. Capacity with Pulse width of 2.3ms

Sorting Bin	Sorting Range	Lowest % of Bin	Lowest E(MV/m)	Kly Pout(kW) with 20% Margin	Pulse Width	Capacity of PS	Pout AV(k W)	Min. Acc Gain(MV)	Uniform Kly Distribution	SB2009 Energy Gain/Bin	SB2009 Kly Av. Power	LC・10Hz(150 GeV Op.)Kly Av P. Weighted Disri	LC・10Hz Kly Av. Power (150GeV Acc)	Possible Rep. No. for Bin	10Hz Energy
		%	MV/m	kW	ms	kw/Bin/kly	kw/Bin/kly	MeV/Bin/kly	Unit	MeV/Bin/kly	kw/Bin/kly	Unit/SB09	kw/Bin/kly	Hz	MeV/Bin/kl
										SB2009		Low Current 10Hz 150GeV			
A	120-112%	112	36.8	814.65	2.30	15.62	15.62	38.14	1.0	38.1	15.62	0.50	7.7	10.10	18.9
B	112-104%	104	34.1	768.35	2.25	15.62	14.40	35.41	1.0	35.4	14.40	0.54	7.7	10.10	19.0
C	104-96%	96	31.5	709.60	2.18	15.62	12.89	32.69	1.0	32.7	12.89	0.60	7.7	10.10	19.6
D	96-88%	88	28.9	653.15	2.11	15.62	11.47	29.96	1.0	30.0	11.47	0.67	7.7	10.10	20.2
E	88-80%	80	26.3	599.05	2.03	15.62	10.15	27.24	1.0	27.2	10.15	0.76	7.7	10.10	20.8
Average		96	31.5	708.96		15.62	12.91	32.69	1.0	32.7	12.91	0.61	7.74		19.6
Total						78.09	64.53	163.44		163.4	64.53		38.68		98.1
Possible Rep(Hz)											5.0		10.00		
E to SB2009										1.0					0.60
Total E (GeV)										250.0					150.0

Basic Configuration of SB2009

All power supplies have a capability of producing the 2.3ms pulse. This results in the cost increase of 18% than the previous model. Cost for SB2009 occupies 73% of RDR HLRF cost.
For heat dissipation, though power supply has a capability of producing the 2.3ms pulse Operation is performed as in the bottom table.

ALL DC Power Supply & Mod. Capacity with Pulse width of 2.3ms

Sorting Bin	Sorting Range	Lowest % of Bin	Lowest E(MV/m)	Kly Pout(kW) with 20% Margin	Pulse Width	Capacity of PS	Pout AV(k W)	Min. Acc Gain(MV)	Uniform Kly Distribution	SB2009 Energy Gain/Bin	SB2009 Kly Av. Power
		%	MV/m	kW	ms	kw/Bin/kly	kw/Bin/kly	MeV/Bin/kly	Unit	MeV/Bin/kly	kw/Bin/kly
										SB2009	
A	120-112%	112	36.8	814.65	2.30	15.62	15.62	38.14	1.0	38.1	15.62
B	112-104%	104	34.1	768.35	2.25	15.62	14.40	35.41	1.0	35.4	14.40
C	104-96%	96	31.5	709.60	2.18	15.62	12.89	32.69	1.0	32.7	12.89
D	96-88%	88	28.9	653.15	2.11	15.62	11.47	29.96	1.0	30.0	11.47
E	88-80%	80	26.3	599.05	2.03	15.62	10.15	27.24	1.0	27.2	10.15
Average		96	31.5	708.96		15.62	12.91	32.69	1.0	32.7	12.91
Total						78.09	64.53	163.44		163.4	64.53
Possible Rep(Hz)											5.0
E to SB2009										1.0	
Total E (GeV)										250.0	

No. of Cavity and HLRF Source

DRFS(SB2009)

Current	4.5	mA		
Electric Field	31.5	MV/m		
Length	1.0377	m		
Power Required			147.1	kW
4 cavities total	4		588.4	kW
Margin or overhead	20	%	706.1	kW
RF eff	100.000	%	706.1	kW
Pulse Width	2.18	ms		

Total ML RF Unit			3640	
1 DRFS Unit Energy Gain			0.131	GeV
e− source			5	GeV
e− RTML			13	GeV
RF. No	1833	e− Cav. No	7332	
A	367	A	1466	
B	367	B	1466	
C	367	C	1466	
D	367	D	1466	
E	367	E	1466	
e− Energy			257.7	GeV
e− Overhead			3.1	%
e+ source			5	GeV
e+ RTML			15	GeV
RF. No	1807	e− Cav. No	7228	
A	361	A	1446	
B	361	B	1446	
C	361	C	1446	
D	361	D	1446	
E	361	E	1446	
e+Energy			256.3	GeV
e− Overhead			2.5	%

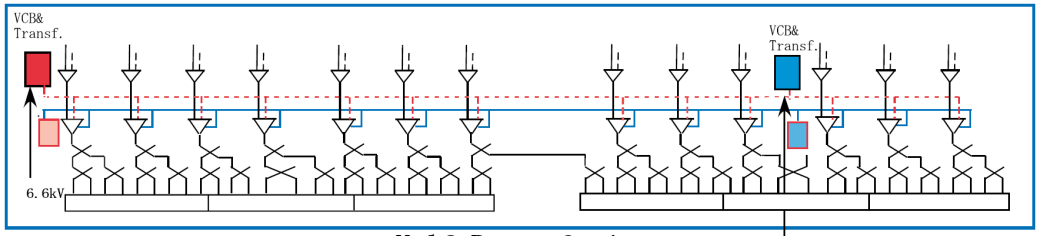
Cost Estimation of DRFS

- Old cost estimation of DRFS(091216) has a scheme that the only switching power supply has a redundancy among 2 DC power supply of 2 BCD units. Then redundancy scheme is changed that 1 backup power supply was introduced in 2 BCD units (100601). This resulted in the actual number of PS and increase the cost.
- In this scheme with SB2009 having the all power supplies of a capacity of 2.3 ms pulse, cost of charger and bouncer circuit increase about SQRT(2.3/1.6) or roughly 18%.

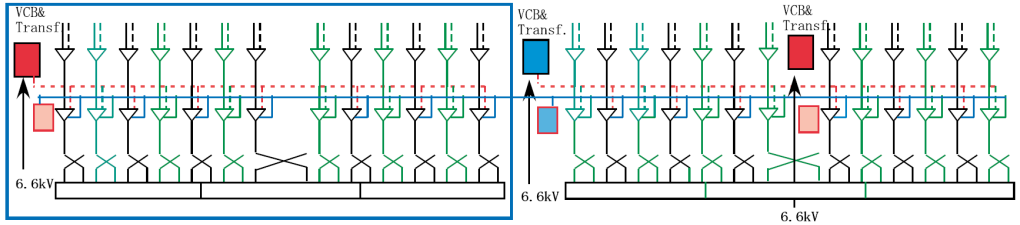
- In the low-current 10Hz operation and 500 GeV reduced bunch operation, the P/Ss of DRFS with a capacity of 2.3 ms pulse are introduced. If the same P/Ss are introduced in full energy operation, though cost is increased, enough RF power may be available. 14% of cost increase is expected.

- If in the upgrade stage, the another specification P/S with shorter pulse capability, 7% of cost increase is expected. For highest bin of cavity sorting, reducing of LLRF or scarifying LLRF feedback might be necessary.

Full energy scheme and cost



Half Power Option



Full Power Option@ 26-Cavities (1 klystron feeds 2 cavities)

DRFS-Cost 110115A
Switching Regulator P/S

2011/1/15
(BAW2)

DRFS	Standard		Low P		Cost Impact
	No@26 Cav	Cost	No@26 Cav	Cost	%
DC PS w Backup	1.5	447	0.75	223	20% Incr
MA Modulator	1.5	90	0.75	60	
MA Klystron	13	845	6.5	423	
PDS	13	91	20	137	
		1473		842	57.2
DRFS/BCD Full		1.27		0.73	
BCD	Standard		Low P		Cost Impact
	No@26 Cav	Cost	No@26 Cav	Cost	%
Mod	1	515	0.5	297	
Kly	1	300	0.5	150	
PDS	1	345	0.5	173	
		1160		620	53.4

Switching Regulator P/S

2011/1/15
(BAW2)

DRFS	Standard		Low P		Cost Impact
	No@26 Cav	Cost	No@26 Cav	Cost	%
DC PS w Backup	1.5	420	0.75	223	20% Incr
MA Modulator	1.5	90	0.75	60	
MA Klystron	13	845	6.5	423	
PDS	13	91	20	137	
		1446		842	58.2
DRFS/BCD Full		1.25		0.73	
BCD	Standard		Low P		Cost Impact
	No@26 Cav	Cost	No@26 Cav	Cost	%
Mod	1	515	0.5	297	
Kly	1	300	0.5	150	
PDS	1	345	0.5	173	
		1160		620	53.4

420 means half PS has 2.3ms pulse capability and other half has 1.65ms pulse capability.

Consideration of Heat Dissipation

Correspond to newest revision:

Full energy operation

- New heat loss evaluation is performed, taking into account for the acceptance of cavity gradient variation in full energy operation.
- We assume that P/S capability hardware follows the condition bellows.
  - either all system of 2.3ms pulse capability or each bin's system with individual pulse width requirement (see Slide No. 8).
  - Pulse width control is performed by MA modulator driver and if the DRFS unit has the same quality's field gradient, all 13 (6.5 in SB2009), it is OK to generate to drive a particular pulse width which is corresponded to the cavity gradient.
- Heat loss evaluation is determined from actual operation. Though highest gradient bin's required average power is increased, averaged power through the 5 sorted bin remains same, and in full energy operation, it is not necessary to increase the heat dissipation from previous estimation.

Heat Loss for Full Energy

Sorting Bin For Cavity 32.8MV/m+-20 Critical Coupling I=9mA

Sorting Bin	Sorting Range	Lowest of Bin(%)	Min. Grad.of Bin	Min. Acc. Gain	Fraction	Coupling	Pulse width	Po/Cav.	2*Po	Overhead	2* Po with 20% overhead
	%	%	MV/m	MV	%		ms	kW	kW	%	MW
A	120-112	112	36.8	38.14	20	Matching	1.80	368.77	737.54	13.3	850.7
B	112-104	104	34.1	35.41	20	Matching	1.76	349.53	699.06	17.8	850.4
C	104-96	96	31.5	32.96	20	Matching	1.71	332.7	665.4	20.0	831.8
D	96-88	88	28.9	29.96	20	Matching	1.66	313.19	626.38	20.0	783.0
E	88-80	80	26.3	27.27	20	Matching	1.61	296.38	592.76	20.0	741.0
Average		96	31.52	32.75			1.71	332.11	664.23		811.36

Total average power through A bin to E bin is same as averaged power of C bin. Heat loss Is proportional to this averaged power.

Consideration of Heat Dissipation

Correspond to newest revision:

Reduced bunch operation: DRFS's case is half current of 4.5mA.

- Very likely hardware specification is come from the "Low energy 10 Hz option" and it is convenient in electron linac that hardware of reduced bunch operation follows them. In positron linac, specification follows either all system of 2.3ms pulse capability or each bin's system with individual pulse width requirement (see Slide No. 8).
- Heat loss evaluation is about half of the full energy version since in reduced bunch version, half number of the klystrons are not installed in this option.
- Heat loss evaluation is determined from actual operation. Though highest gradient bin's required average power is increased, averaged power through the 5 sorted bin remains same, and in full energy operation, it is not necessary to increase the heat dissipation from previous estimation. This is the same situation as the case of full energy operation.

Heat Loss for Reduced Bunch Operation

ALL DC Power Supply & Mod. Capacity with Pulse width of 2.3ms

Sorting Bin	Sorting Range	Lowest % of Bin	Lowest E(MV/m)	Kly Pout(kW) with 20% Margin	Pulse Width	Capacity of PS	Pout AV(k W)	Min. Acc Gain(MV)	Uniform Kly Distribution	SB2009 Energy Gain/Bin	SB2009 Kly Av. Power
		%	MV/m	kW	ms	kw/Bin/kly	kw/Bin/kly	MeV/Bin/kly	Unit	MeV/Bin/kly	kw/Bin/kly
										SB2009	
A	120-112%	112	36.8	814.65	2.30	15.62	15.62	38.14	1.0	38.1	15.62
B	112-104%	104	34.1	768.35	2.25	15.62	14.40	35.41	1.0	35.4	14.40
C	104-96%	96	31.5	709.60	2.18	15.62	12.89	32.69	1.0	32.7	
D	96-88%	88	28.9	653.15	2.11	15.62	11.47	29.96	1.0	30.0	11.47
E	88-80%	80	26.3	599.05	2.03	15.62	10.15	27.24	1.0	27.2	10.15
Average		96	31.5	708.96		15.62	12.91	32.69	1.0	32.7	
Total						78.09	64.53	163.44		163.4	64.53
Possible Rep(Hz)											5.0
E to SB2009										1.0	
Total E (GeV)										250.0	

Total average power through A bin to E bin is same as averaged power of C bin. Heat loss Is proportional to this averaged power.

Summary

- Reduced bunch operation in DRFS are presented. Since DRFS configuration is strongly linked with other operation mode, discussion is proceeded combined with low-current 10Hz operation and reduced bunch operation.
- Effect of prolonging the pulse width and accepting the cavity field gradient variation, serious modification in HLRF are introduced.
- Specification of all P/S which have a capability with 2.3ms pulse is used. This is operable for all sorting cavity bin and in low energy operation, 10Hz is available. Cost of 18 % is increased. If in the future upgrading pass, there are two hardware expanding ways associating the P/S capability.
- Data of heat dissipation is also presented. For average power view point, there are no serious change.