



ILC Marx Modulator The Technology of Choice

G.E. Leyh, Stanford Linear Accelerator Center

ILC Modulator Specifications

Pulse Voltage

Pulse Current

Pulse Length [flat-top]

Total Pulse Charge

Total Pulse Energy

Repetition Rate

Average AC Input Power

Total # of Stations

120 kV

140 A

1370 uS

192 mC

23,520 J

5 Hz

125 kW

576

Baseline 10MW TTF Modulator



Developed in the early 90's at FermiLab for use with the TTF.

Currently in use at FNAL and on the XFEL at DESY.

Uses a passive 'bouncer' circuit to compensate for capacitor droop.

Advantages:

- Simple circuit topology
- Proven design; 10+ years of operation

Disadvantages:

- Mechanically complex
- Massive pulse transformer 6.5 tons
- Requires large floor area
- Insulating oil 100's of gallons

Marx Advantages – Efficiency

- Much lower switch currents (140A vs >1600A)
- Switches operate only once per pulse
 - Highest efficiency avoids switching losses
 - Improves reliability switching events are high risk
- No core losses or reset circuitry
- Higher waveform efficiency

G.E. Leyh

96-98% stack efficiency, based on measurements of switch losses under full pulse width and current

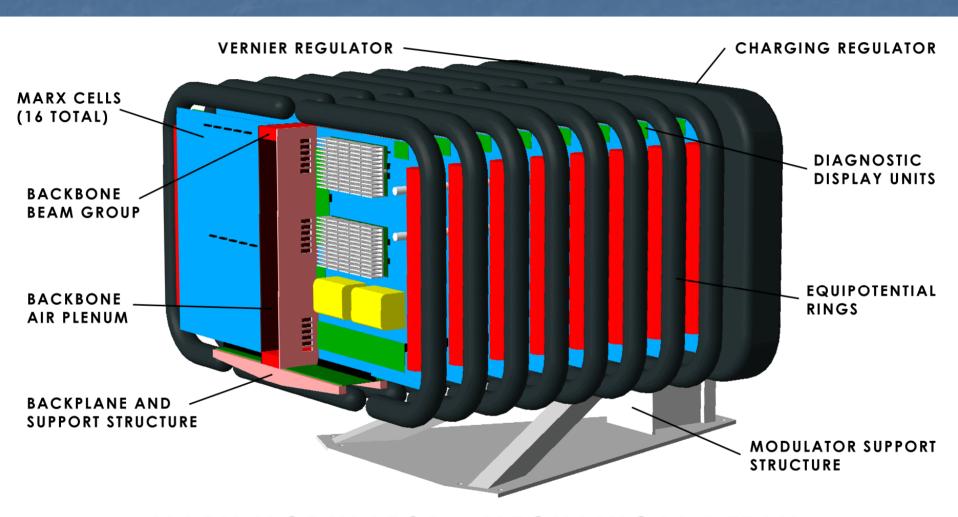
Marx Advantages – Site Installation Costs

- Compact size requires 1/3 the floor space
- No oil required
 - Saves 100's of gallons per modulator
 - Avoids safety and environmental issues
- Simplified modulator enclosure requirements
- Modular construction improves tunnel transport

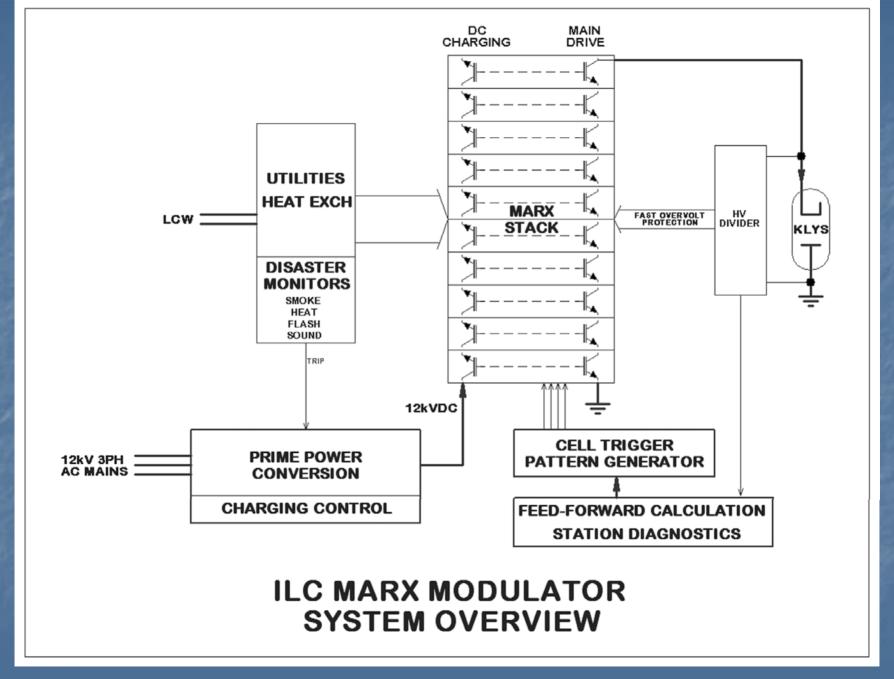
Marx Advantages – Modular Design

- Increased availability
 - Marx Stack can work around failures
 - Modular Design reduces MTTR
- Allows printed-circuit integration
 - Greatly reduces assembly costs
 - Streamlines QC processes
- Reduces inventory of spare components

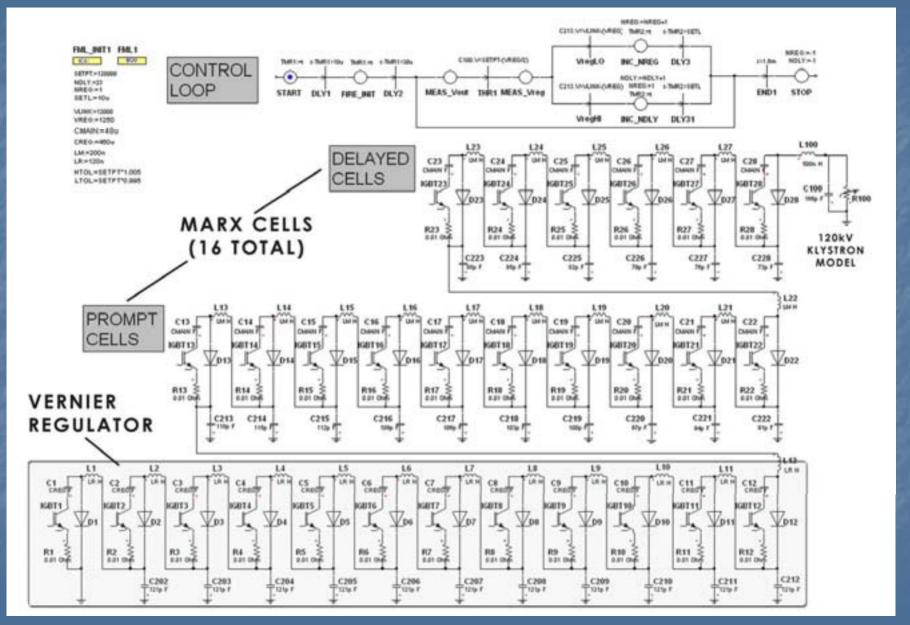
ILC Marx Modulator Layout



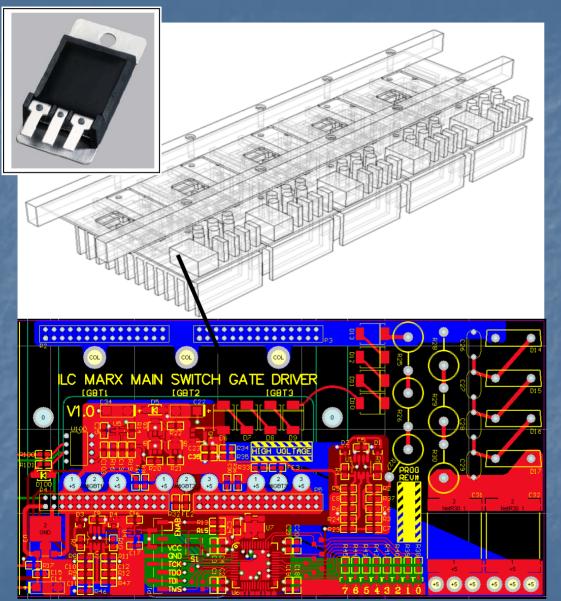
MARX MODULATOR - MECHANICAL DETAIL



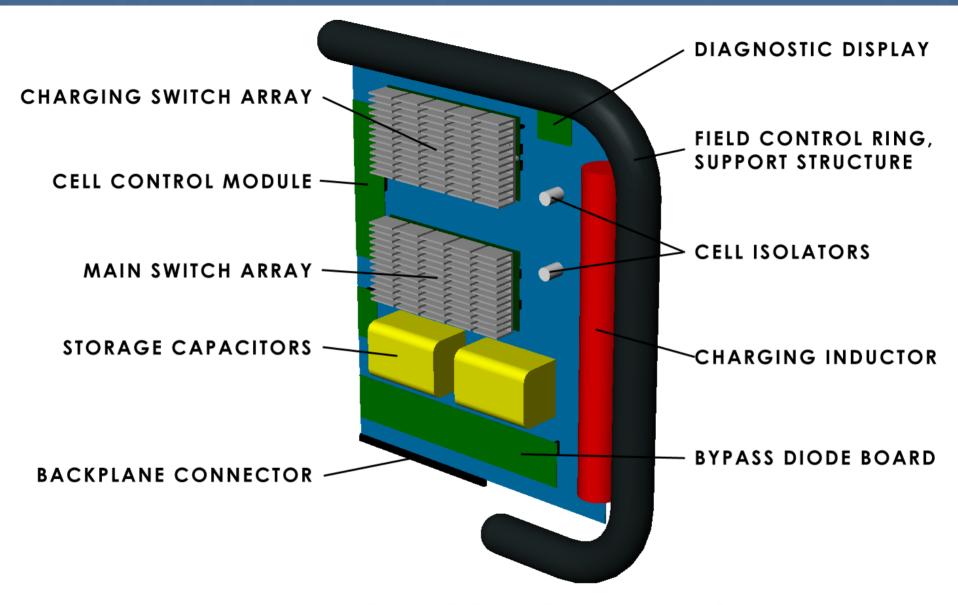
Schematic – Marx Stack



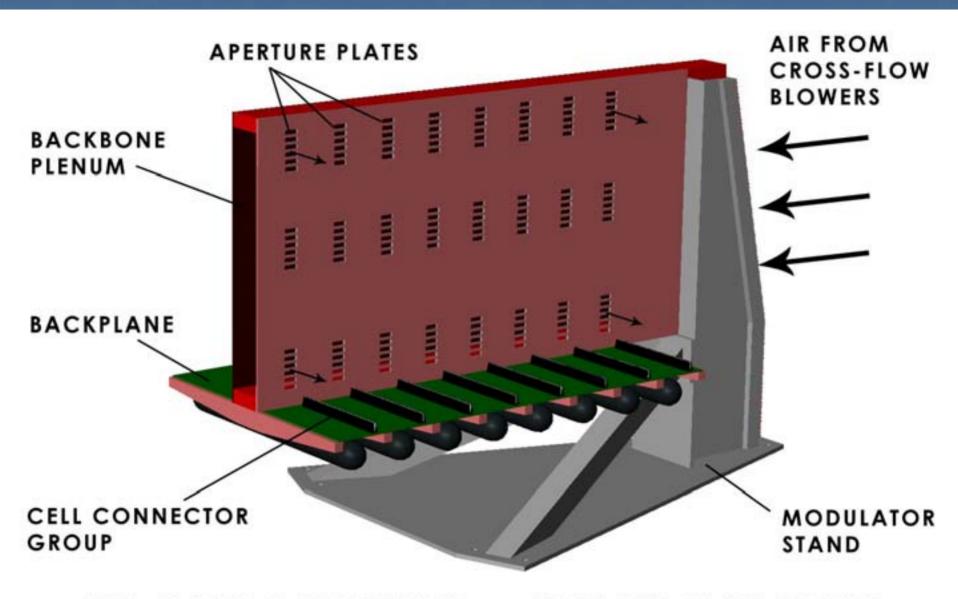
12kV Solid-State IGBT Switch



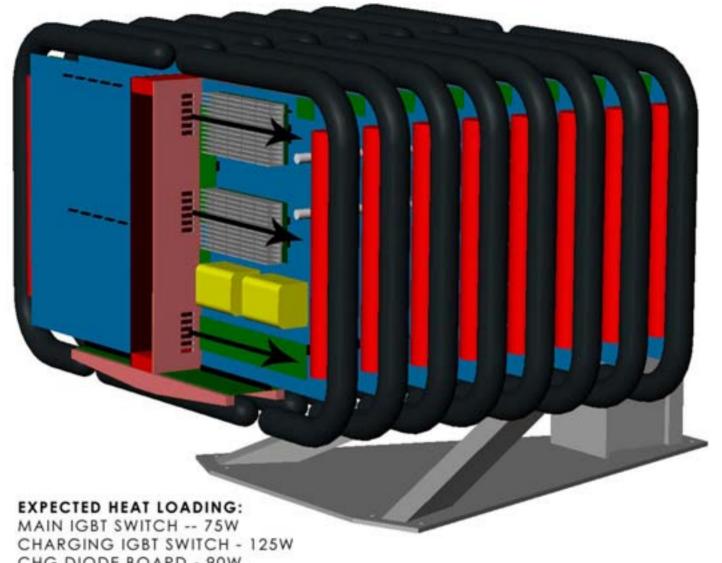
- 5-section modular PC-board design, using 4500V Single-Die IGBTs
- Each section has independent gate drivers, delay stabilization circuitry, overvoltage protection and snubbing networks
- Switch designed to operate at full spec with one failed section
- Overcurrent protection with multiple threshold/delay setpoints



MARX CELL COMPONENT LAYOUT



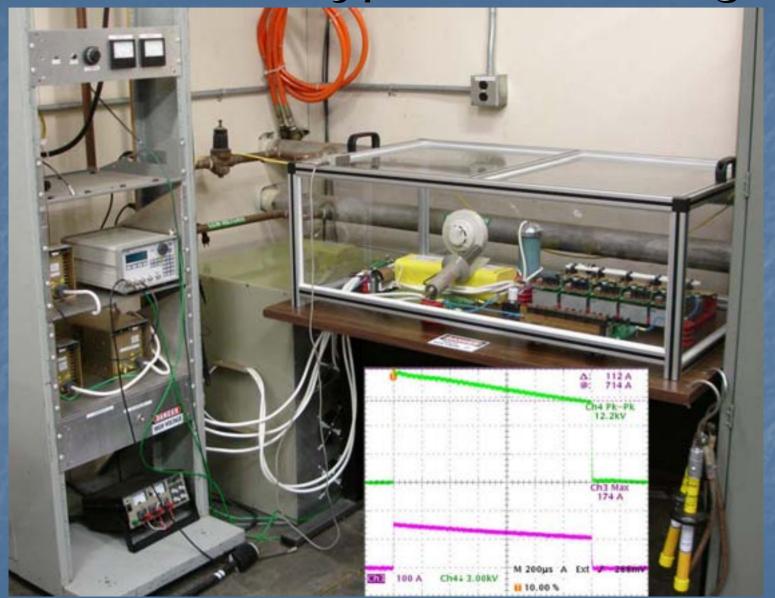
ILC MARX MODULATOR -- AIRFLOW PLAN DETAIL

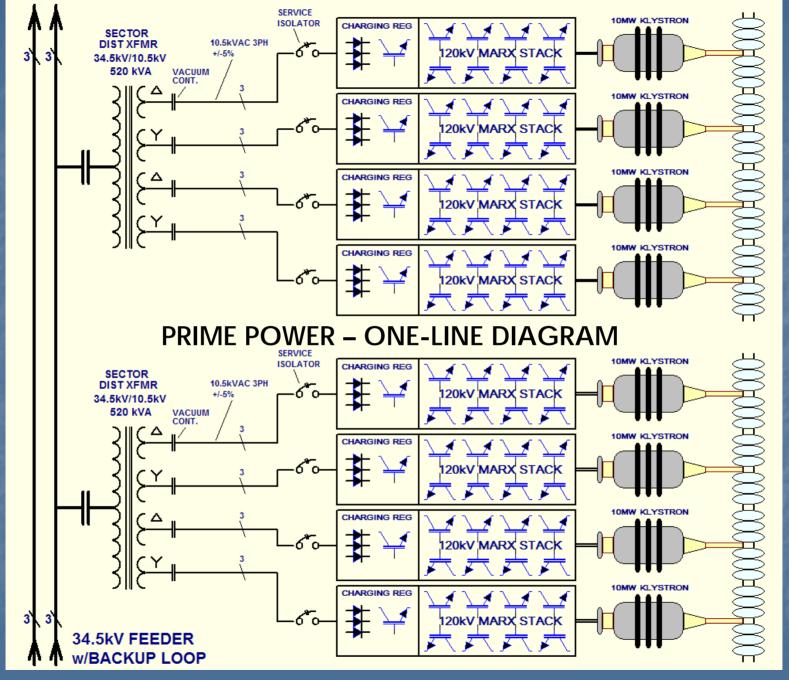


CHG DIODE BOARD - 90W

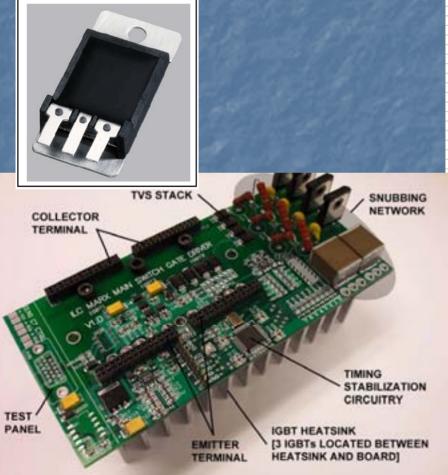
AIRFLOW PATTERN FROM BACKBONE PLENUM ACROSS IGBT MODULES AND CHG DIODE BOARD

Marx Prototype Cell Testing



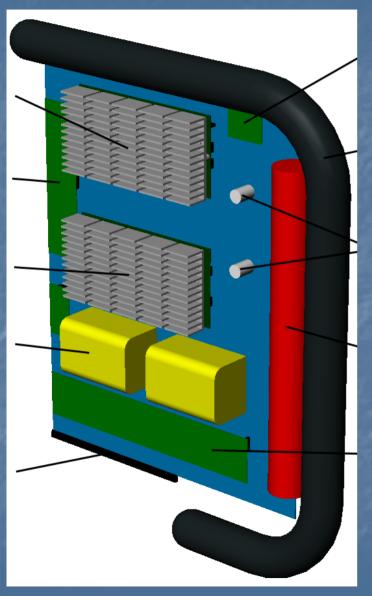


Costing – IGBT Module Level



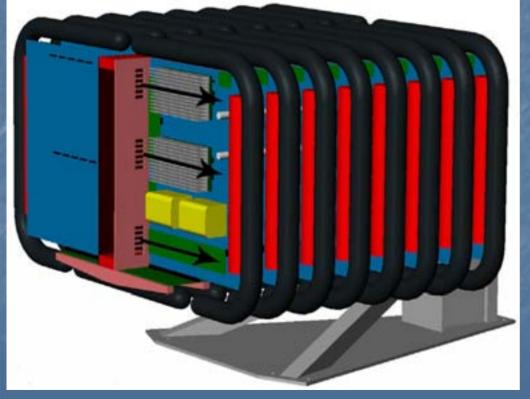
QUAN (PER BD. 3 4 19 4 4 2 2 4 3 8 9 2 3	480 640 3040 640 320 320 640	100p 100n 10n 0.1u 33u 100p	PN# PCC101CGCT-ND PCC222BNCT-ND	VENDOR	QUAN	DATE	RCVD	UNIT \$	ORDER \$
3 4 19 4 4 2 2 2 4 3 8 9	480 640 3040 640 640 320 320	10n 0.1u 33u	PCC222BNCT-ND	DIGIVEY					
4 19 4 4 2 2 4 3 8 9	640 3040 640 640 320 320	10n 0.1u 33u	PCC222BNCT-ND	DIGI VEV					
4 19 4 4 2 2 4 3 8 9	640 3040 640 640 320 320	10n 0.1u 33u	PCC222BNCT-ND		480			0.224	108
19 4 4 2 2 2 4 3 8 9	3040 640 640 320 320	0.1u 33u		DIGI-KEY	640			0.168	108
2 2 4 3 8 9	640 320 320		PCC1840CT-ND	DIGI-KEY	3040			0.073	222
2 2 4 3 8 9	320 320	100p	478-1735-1-ND	DIGI-KEY	640			1.824	1167
2 4 3 8 9 2	320		P4474A-ND	DIGI-KEY	640			0.355	227
4 3 8 9 2		33n 5kV	7565B333K502NX	NOVACAP	320			10.000	3200
3 8 9 2	640	3	805		320			0.025	8
8 9 2	480	4.7 75	805 805		640 480			0.025 0.025	16 12
9 2	1280	120	805		1280			0.025	32
	1440	1K	805		1440			0.025	36
3	320	3K	805		320			0.025	8
	480	11K	805		480			0.025	12
4	640	270K	805		640			0.025	16
3	480	33K	PPC33KW-3JCT-ND	DIGI-KEY	480			0.305	146
3	480	1M	PPC1.0MW-3JCT-ND	DIGI-KEY	480			0.305	146
4	640	BAV99	BAV99DICT-ND	DIGI-KEY	640			0.208	133
3	480	ES2DA	ES2DADICT-ND	DIGI-KEY	480			0.456	219
8	1280 640	DO214AB 60D100B	1.5SMC540A APT60D100B	VISHAY APT	1280 640			0.301 2.340	385 1498
3	480	390nH	334-1079-1-ND	DIGI-KEY	480			0.330	158
4	640	12PIN HD	9815F-ND	DIGI-KEY	640			1.370	877
8	1280	SOT-23	67-1665-1-ND	DIGI-KEY	1280			0.435	557
3	480	VN3205	VN3205N8	SUPERTEX	480			0.147	71
1	160	VN3203	VP3203N8	SUPERTEX	160			0.147	24
1	160	SVITCHEVQ	P8047SCT-ND	DIGI-KEY	160			0.599	96
2	320	LT1720CS8		LINEAR TECH	320			1.590	509
1	160	7805CKTER	296-11108-1-ND	DIGI-KEY	160			0.298	48
1	160	LP2985AIM5-3.3	LP2985AIM5-3.3CT-ND	DIGI-KEY	160			0.357	57
1	160	MIC5235	MIC5235BM5	MICREL	160			0.455	73 336
1	160	XCR3032XL CSX750PBC	CSX750PBC-ND	XILINX DIGI-KEY	160 160			2.100 2.970	475
Ö	0		HCPL2611W-ND	DIGI-KEY	0			0.567	0
0	0	NTA1215	C&D	800-543-8630	0			2.700	0
3	480	QIS450602	QIS4506001	POVEREX	480			83.250	39960
MECHAI	NICAL								
		DOD CLATCHIO		COLOCKTO	100			05.000	4000
0.333	160 53.28	PCB, SWITCH30 AL HEATSINK EXTRU	00140	COLO CKTS AAVID	160 53			25.000 15.000	4000 799
1	160	MACHINED HEATSIN		SMPCO	160			30,000	4800
2	320		BER134-ND	DIGI-KEY	320			1.000	320
3	480	IGBT SPACER	90309A819	McMasterCarr	480			0.470	226
3	480	SCREW, 10-32x7/8", AL	91251A346	McMasterCarr	480			0.116	56
4	640	SCREW, 4-40x 1/4", TR	91770A092	McMasterCarr	640			0.030	19
						COST	PER M	ODULE	382.2
				IODT MODULE	MOC				
				IGBT MODULE		TOTAL	MODU	LATOR	61158.2
LABO	OR, M	ODULE A	SSEMBLY	AND TESTI	NG				
		PROCEDURE		TIME, hr/unit	\$/hr			UNIT \$	ORDER \$
		SURFACE-MOUNT PL	ACEMENT	0.10	25			2.50	400
		THROUGH-HOLE PLA		0.20	25			5.00	800
		MECHANICAL ASSEN	//BLY	0.25	25			6.25	1000
		MODULE TESTING AN	ID CALIBRATION	0.15	25			3.75	600
					L	ABOR.	PER M	ODULE	17.5
				IGBT MODULE LA					2800
				ISST MIODULE L	ABUK,	TOTAL	WIODU	LATOR	2000

Costing – Marx Cell Level



BIL	L OF	MATERIAL	_S, MAR	X CELL	ORDE	RING	INFO		
QUAN	QUAN X	COMPONENT	PN#	VENDOR	QUAN	DATE	RCVD	UNIT \$	ORDER
PER BD.	16								
2	32	100u, 6k∀	06MV0003-A	CSI	32			240.00	768
10	160	0.1u	PCC1840CT-ND	DIGI-KEY	160			0.11	1
2	32	0.27u	EF6274-ND	DIGI-KEY	32			0.11	10
1	16	DIODEFWD30	MODULE	SLAC	16			157.42	251
1	16	DIODECHG30	MODULE	SLAC	16			225.84	3613
1	16	DIODECHG30	MODULE	SLAC	16			100.00	1600
10	160	IFD96	WIODOLE	INDUSTRIAL FIBER OPTICS	160			5.10	816
10	160	IFE91D		INDUSTRIAL FIBER OPTICS	160			2.50	400
		===			32				
2	32	RELAY15KV		GIGAVAC				220.00	7040
1	16	LCHG	140DU E	SCIENTIFIC CONVERSION	16			250.00	4000
1	16	MODCONTROL30	MODULE	SLAC	16			129.83	2077
1	16	MODPRE-REG30	MODULE	SLAC	16			43.47	695
11	16	MODDISPLAY30	MODULE	SLAC	16			46.37	742
1	16	SUPPLY300V	VI-RJ6011-EZZZ	VICOR	16			344.00	5504
3	48	50M, 7.5W DIVIDER	MOX3-125005F	OHMITE	48			7.50	360
2	32	20m		ISOTEK	32			25.00	800
10	160	180			160			0.03	4
10	160	IGBT MODULE	MODULE	SLAC	160			382.24	61158
14	224	CST206	CST206-1T	TRIAD ALLIED ELECS	224			4.50	1008
1	16	ISOXFMR	SC205-03	SCIENTIFIC CONVERSION	18	22-Aug		210.00	3780
9	144	CONNECTOR, PCB, 20PIN		SAMTEC	144			1.59	229
46	736	CONNECTOR, PCB, 12PIN		SAMTEC	736			1.35	993
10	160	FIBER-OPTIC CABLE		INDUSTRIAL FIBER OPTICS	160			0.40	64
MECH	ANICAL								
1	16	PCB, CELL30			16			600.00	9600
1	16	BACKING FRAME			16			350.00	5600
1	16	EQUIPOTENTIAL RING			16			250.00	4000
1	16	INJ/EXT ASSEMBLY			16			400.00	6400
		III HOLENCE I			10				0400
						M	&S PEF	CELL	8169.7
				CELL	M&S, 7	TOTAL	MODU	LATOR	130716
LAE	BOR.	ASSEMBL'	Y AND 1	resting					
		PROCEDURE		TIME, hr/unit	\$/hr			UNIT \$	ORDER \$
		ROCEDORE		inac, mant	ΨΠΠ			OI4II Ø	OKDEK 4
		FROM IGBT MODULE LABO	⊥ DR	7.0	25			175.00	2800
		FROM DIODE AND CONTRO	L MODULE LABOR	2.1	25			52.50	840
		CELL BOARD: THRU-HOLE		0.4	25			10.00	160
		CELL BOARD: MODULE PLA		0.2	25			5.00	80
		CELL BOARD: MECHANICA		1.0	25			25.00	400
		CELL BOARD: TESTING AN		0.3	25			7.50	120
						LABOR, PER CELL			275.0
				OF!!!	ADOD 7				
				CELL L	ABUK.	IUIAL	MODU	LATOR	4400

Costing – Marx Modulator Top Level



BOM, MODULATOR TOP LEVEL

\$/MOD

MARX CELL STACK

				·····	
FROM IGBT MODULES TOTAL M&S				61158	
FROM DIODE AND CONTROL MODU	_M&S		11247		
FROM CELL COMPONENTS TOTAL N	v1&S			58311	
		MAR	X CELL ST	ACK M&S	130716
VERNIER REGULATOR			16		
DESCRIPTION	\$EA	#/CELL	#/REG	\$/MOD	
CAP,750u 1200V	28	1	16	448	
DIODE, 60D100	3.39	4	64	217	
IGBT, 19N250	12.4	3	48	595	
HEATSINK, 19N250	7.5	3	48	360	
HEATSINK, 60N100	6.5	4	64	416	
CELL CONTROL MODULE	80	1	16	1280	
CURRENT SHUNT	21	2	32	672	
INDUCTOR, CHARGING	11	1	16	176	
RELAY, 1200V	17	1	16	272	
CONNECTOR GROUP	3.5	2	32	112	
PCB, MAIN	250		1	250	
CASE, OUTER SHIELD	1200		1	1200	
MISC FIXTURING, HDWR	350		1	350	
			VERNIER	REG M&S	6348
SYSTEM LEVEL					
CHARGING REGULATOR MODULE	8600			8600	
GROUND STATION HDWR	5350			5350	
AIR-WATER EXCHANGER	5500			5500	
GND STAT RF	880			880	
GND STAT SIGNAL PROCESSING	4210			4210	
AIR CIRCULATION/FILTERING	5800			5800	
ENVIRONMENTAL MONITORS	2000			2000	
MODULATOR STRUCTURAL	1500			1500	
MODULATOR MAIN ENCLOSURE	2200			2200	
			YSTEM LE	36040	
		MODU	LATOR TO	TAL M&S	173104

LABOR, MODULATOR TOP LEVEL

•					
PROCEDURE		TIME	\$/hr	\$/MOD	
FROM IGBT MODULE LABOR				2800	
FROM DIODE AND CONTROL MODU	LE LABOR			840	
FROM CELL LABOR				760	
MECHANICAL INTEGRATION, STRUC	TURAL	25	25	625	
MECHANICAL INTEGRATION, ENCLO	SURE	35	25	875	
MECHANICAL INTEGRATION, OTHER	₹	60	25	1500	
TESTING AND CALIBRATION		15	35	525	
		MODULA	TOR TOTA	AL LABOR	792

MODULATOR TOTAL M&S + LABOR 181029