



# **ILC Marx Modulator**

## **The Technology of Choice**

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# ILC Modulator Specifications

Pulse Voltage	120 kV
Pulse Current	140 A
Pulse Length [flat-top]	1370 $\mu$ S
Total Pulse Charge	192 mC
Total Pulse Energy	23,520 J
Repetition Rate	5 Hz
Average AC Input Power	125 kW
Total # of Stations	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  $>1600\text{A}$ )
- 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
- 96-98% stack efficiency, based on measurements of switch losses under full pulse width and current

# Marx Advantages – Site Installation Costs

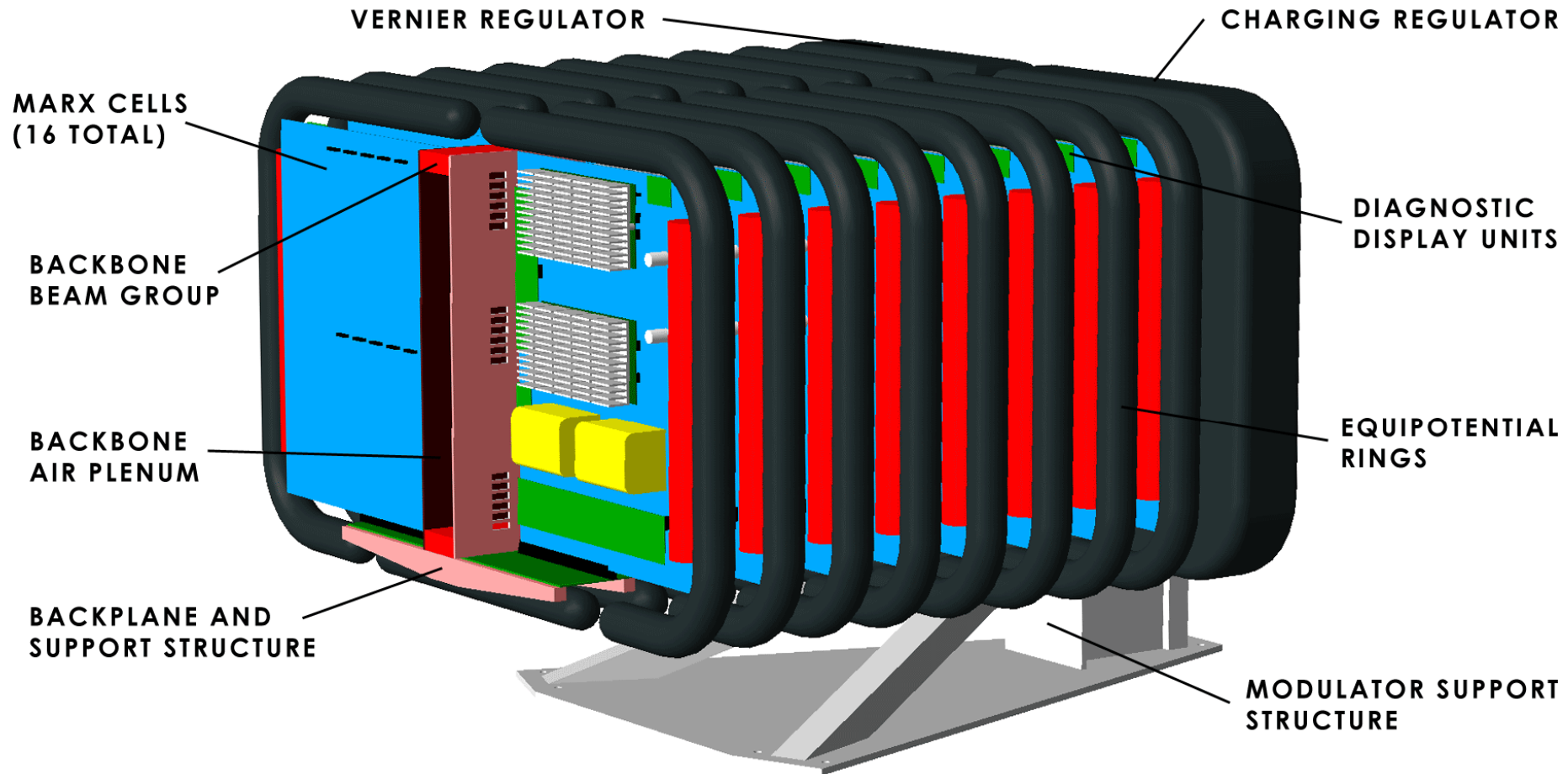
- Compact size – requires 1/3 the floor space
- No oil required
  - Saves 100's of gallons per modulator
  - Avoids safety and environmental issues
- Simplified modulator enclosure requirements
- Modular construction improves tunnel transport

# Marx Advantages – Modular Design

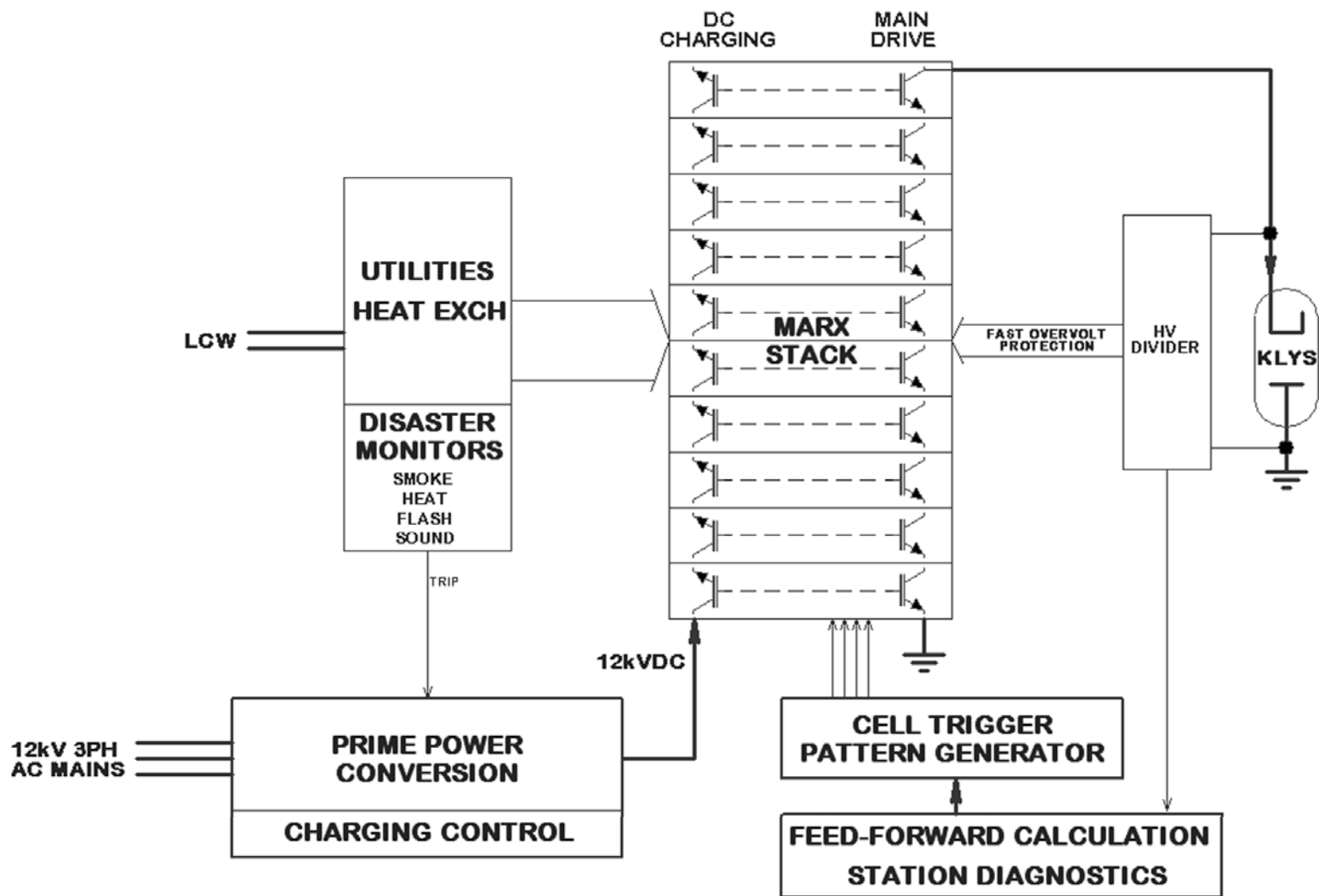
- Increased availability
  - Marx Stack can work around failures
  - Modular Design reduces MTTR
- Allows printed-circuit integration
  - Greatly reduces assembly costs
  - Streamlines QC processes
- Reduces inventory of spare components



# ILC Marx Modulator Layout



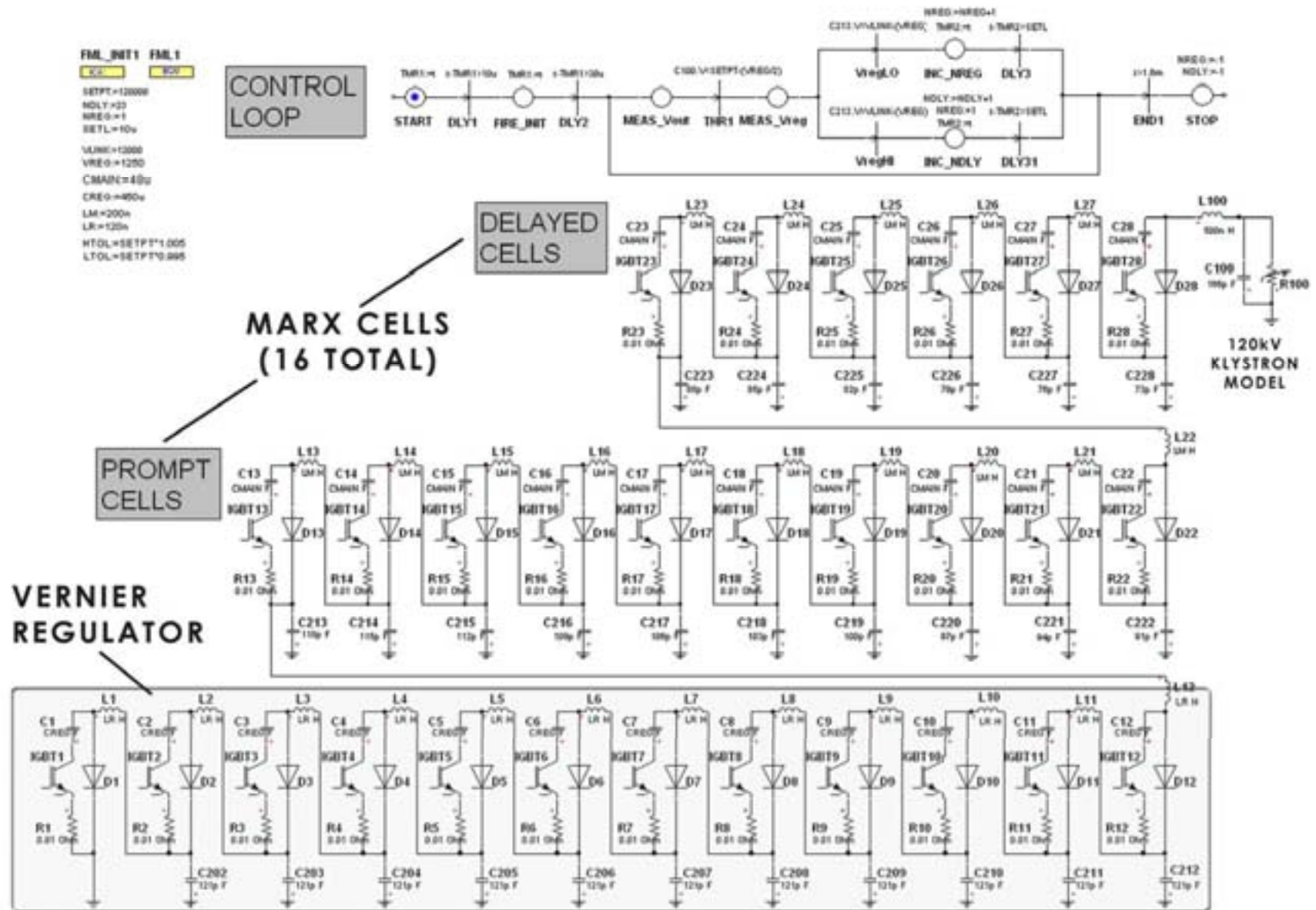
## MARX MODULATOR - MECHANICAL DETAIL



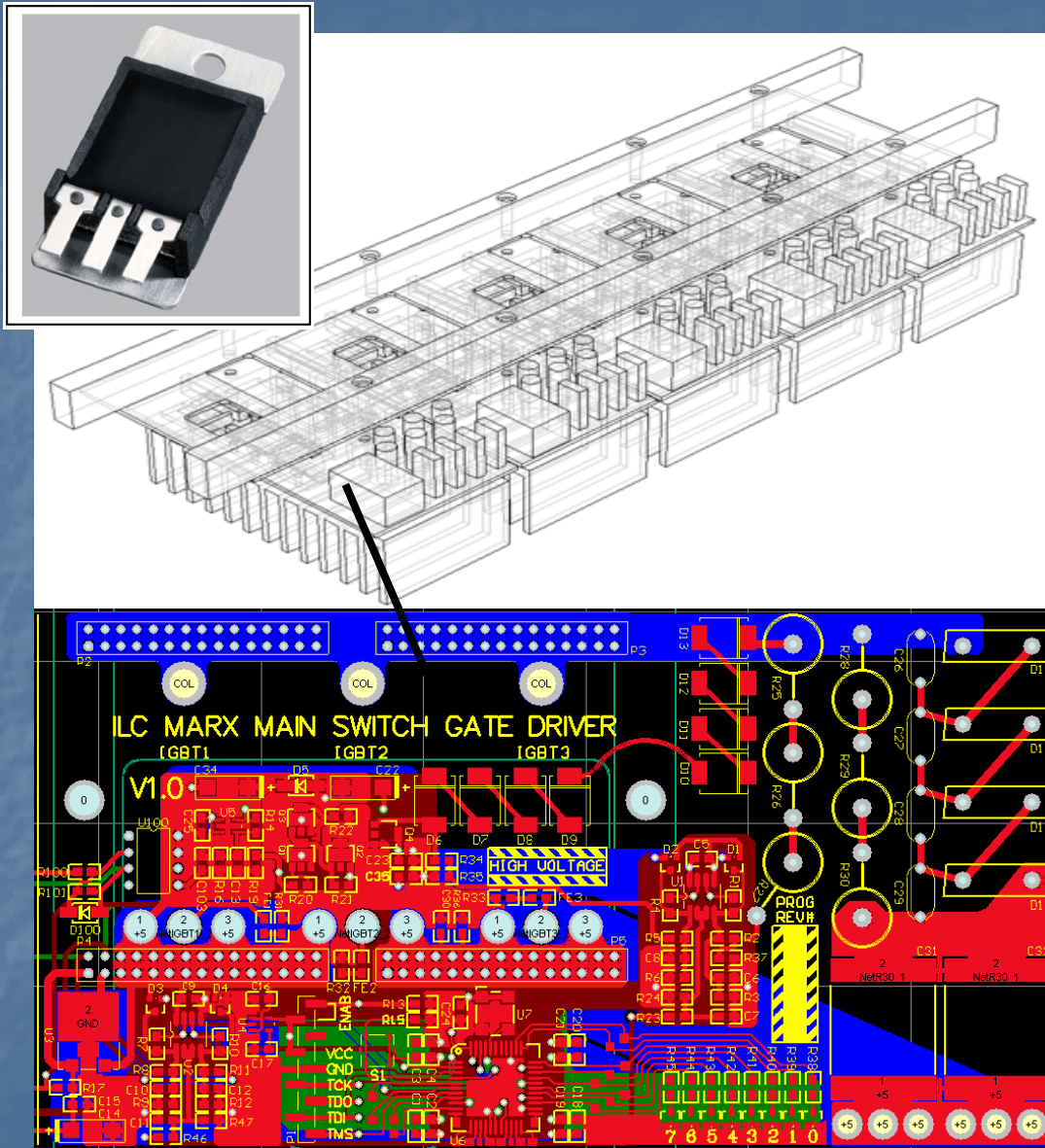
## ILC MARX MODULATOR SYSTEM OVERVIEW



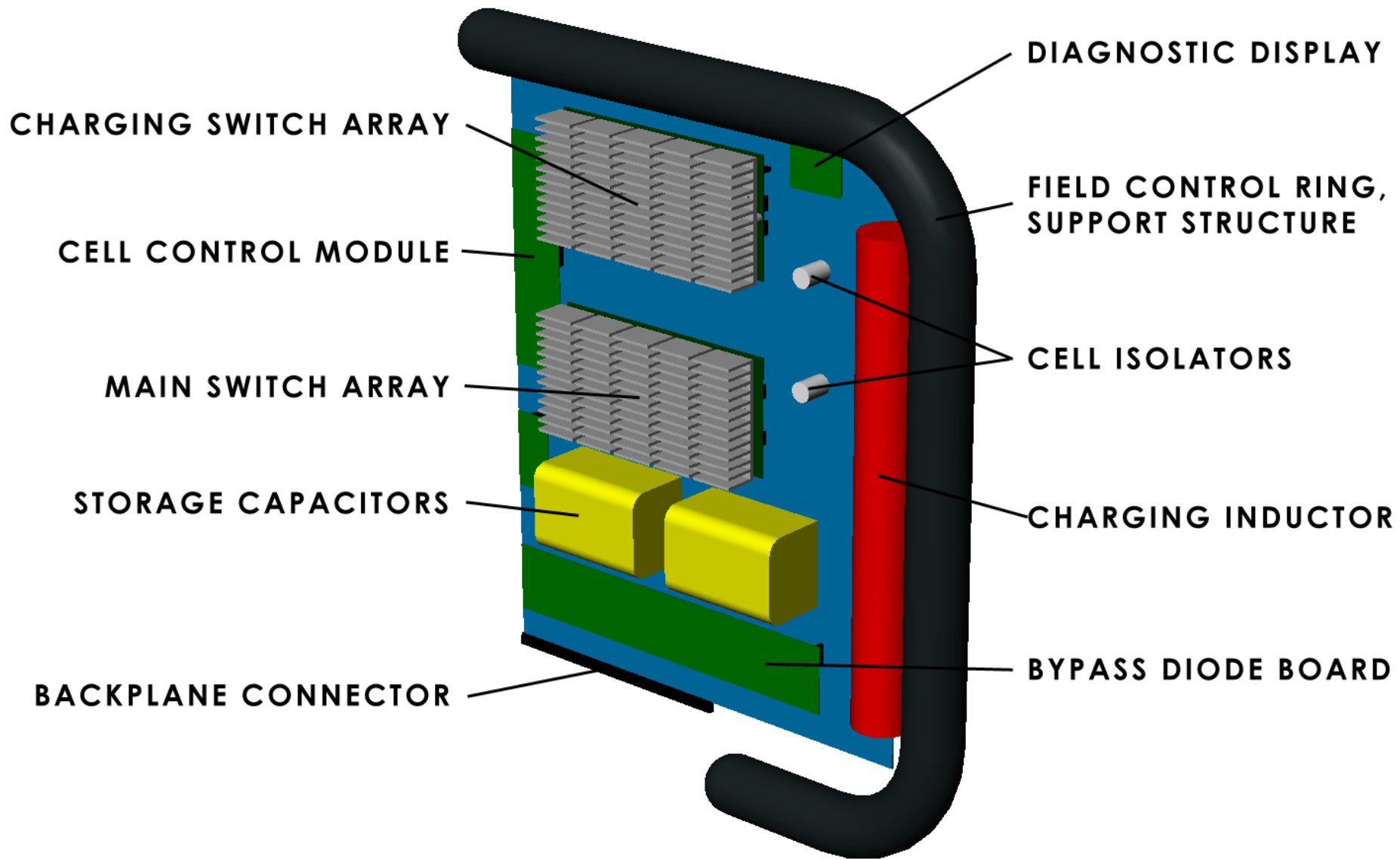
# Schematic – Marx Stack



# 12kV Solid-State IGBT Switch

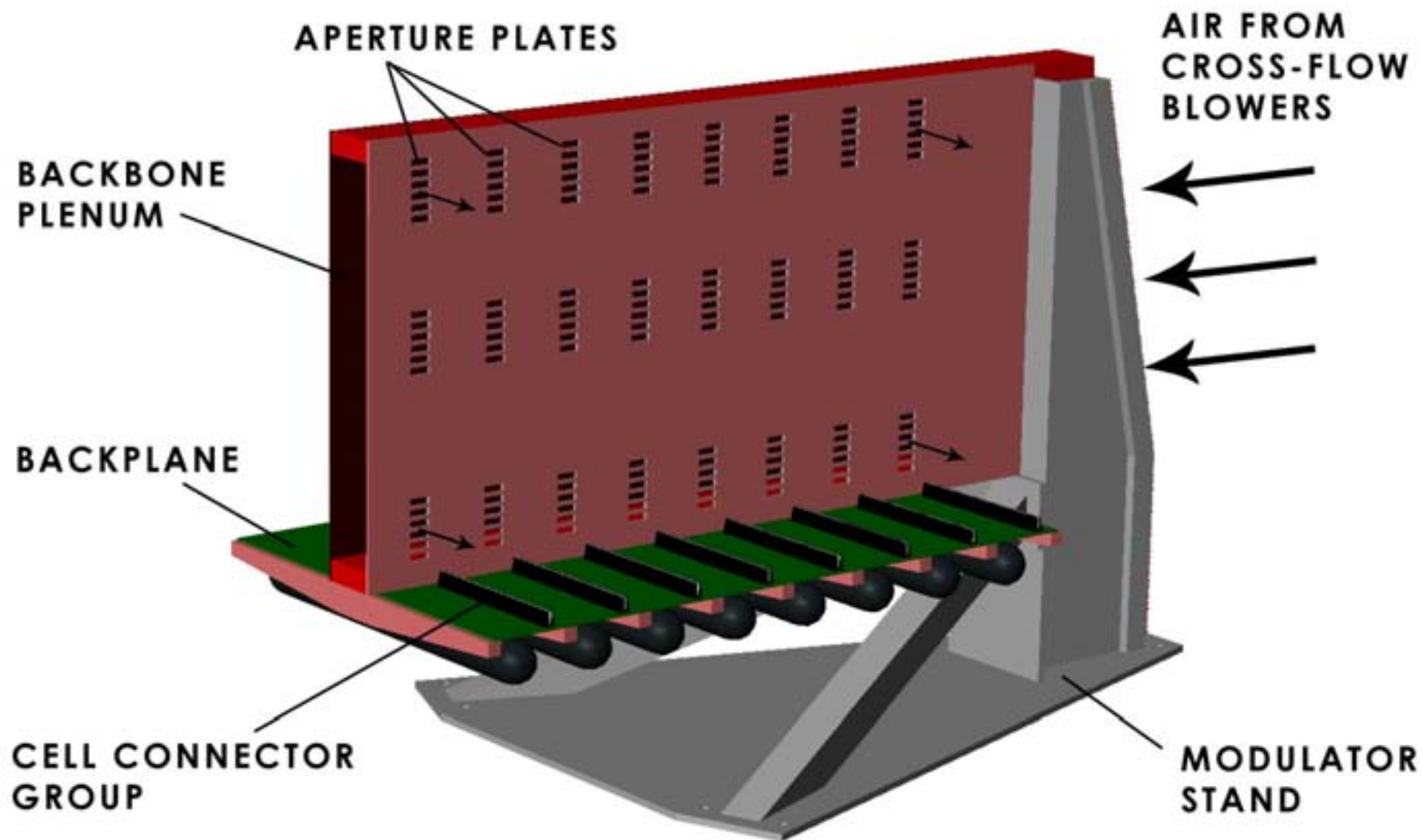


- 5-section modular PC-board design, using 4500V Single-Die IGBTs
- Each section has independent gate drivers, delay stabilization circuitry, overvoltage protection and snubbing networks
- Switch designed to operate at full spec with one failed section
- Overcurrent protection with multiple threshold/delay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

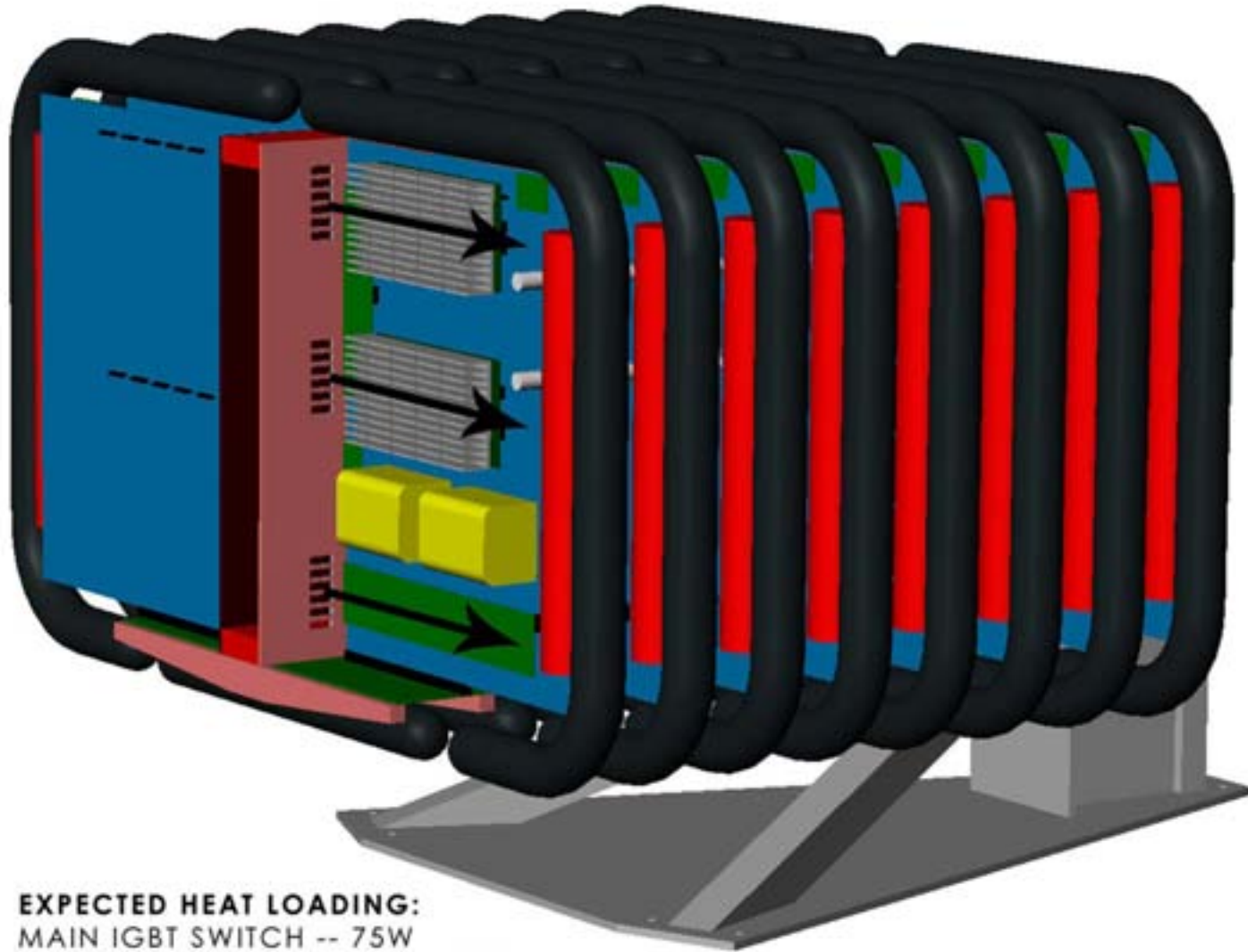


## MARX CELL COMPONENT LAYOUT





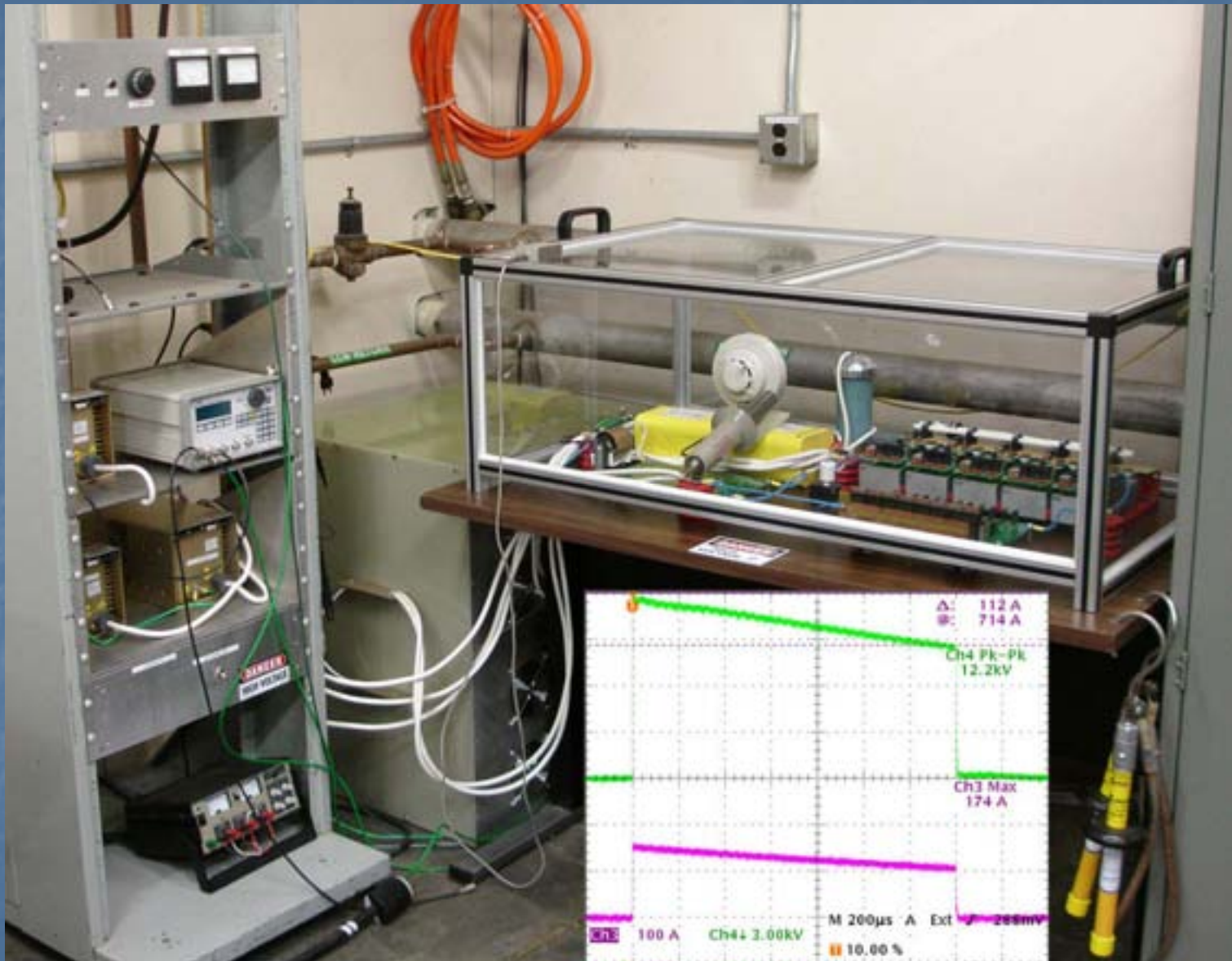
**ILC MARX MODULATOR -- AIRFLOW PLAN DETAIL**



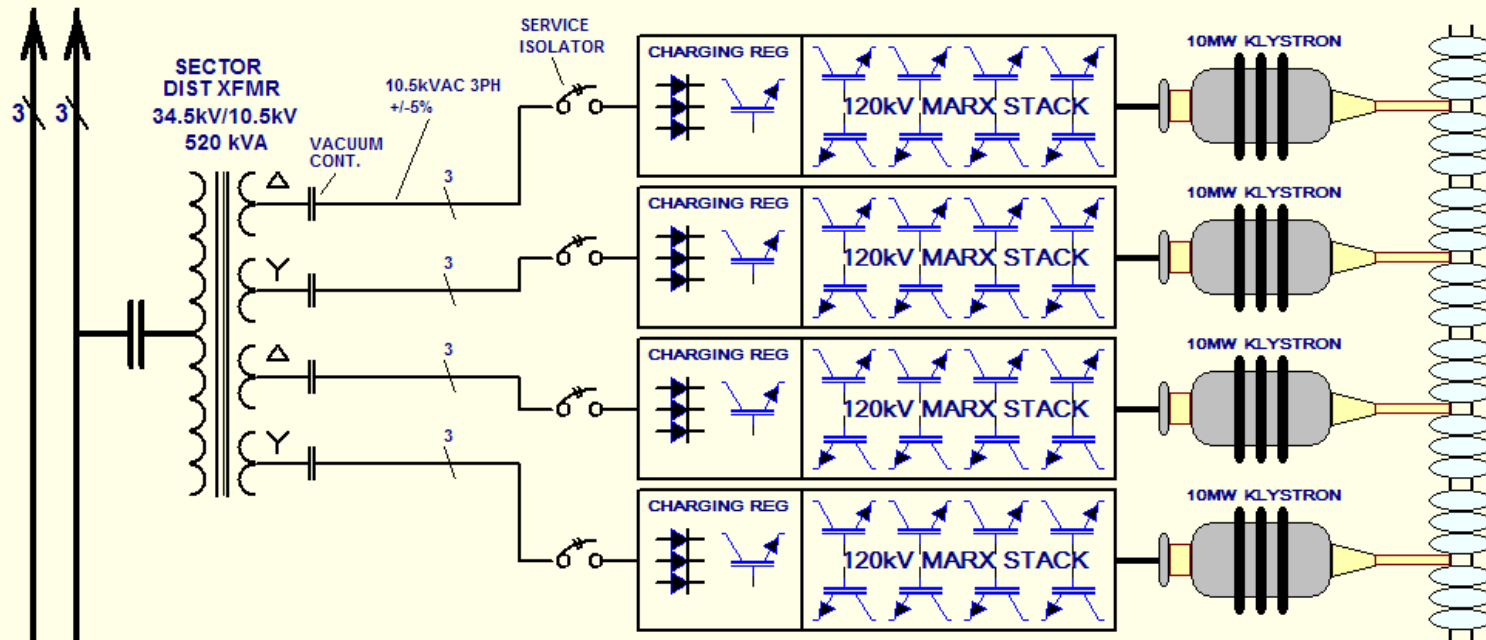
**EXPECTED HEAT LOADING:**  
MAIN IGBT SWITCH -- 75W  
CHARGING IGBT SWITCH - 125W  
CHG DIODE BOARD - 90W

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

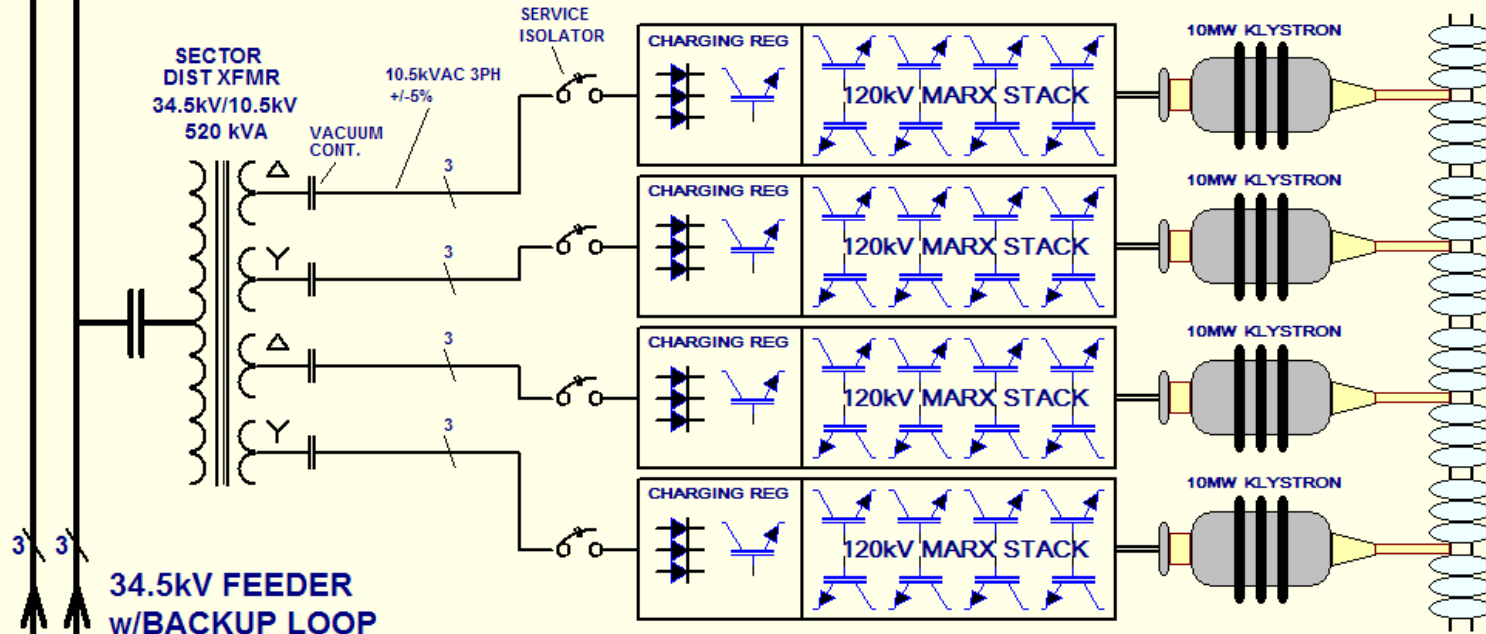
# Marx Prototype Cell Testing



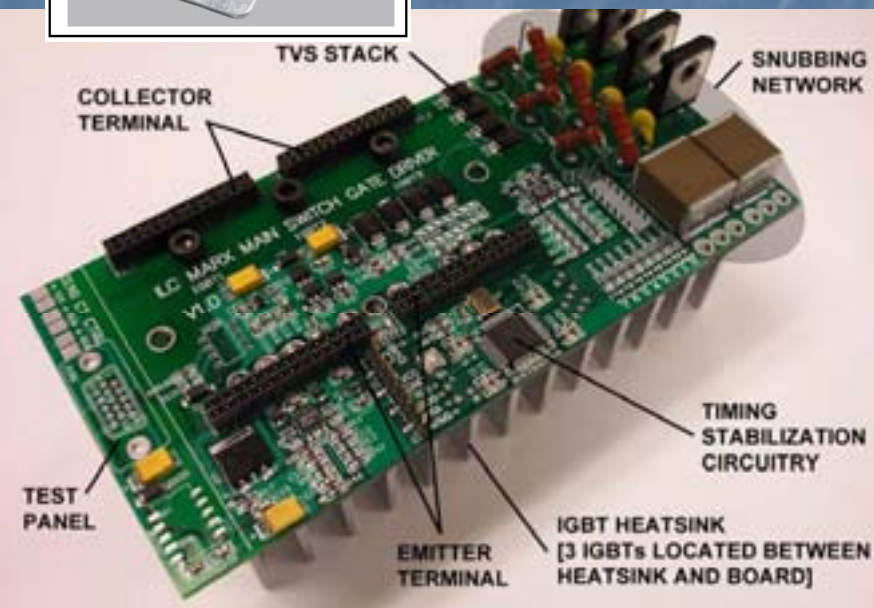




## PRIME POWER – ONE-LINE DIAGRAM



# Costing – IGBT Module Level



## BILL OF MATERIALS, IGBT MODULE

QUAN	QUAN X	COMPONENT	PN#	VENDOR	QUAN	DATE	RCVD	UNIT \$	ORDER \$
PER BD.	160								
3	480	100p	PCC101CGCT-ND	DIGI-KEY	480			0.224	108
4	640	10n	PCC222BNCT-ND	DIGI-KEY	640			0.168	108
19	3040	0.1u	PCC1840CT-ND	DIGI-KEY	3040			0.073	222
4	640	33u	478-1735-1-ND	DIGI-KEY	640			1.824	1167
4	640	100p	P4474A-ND	DIGI-KEY	640			0.355	227
2	320	33n 5k V	7565B33K502NX	NOVACAP	320			10.000	3200
2	320	3	805		320			0.025	8
4	640	4.7	805		640			0.025	16
3	480	75	805		480			0.025	12
8	1280	120	805		1280			0.025	32
9	1440	1K	805		1440			0.025	36
2	320	3K	805		320			0.025	8
3	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	PPC10MW-3JCT-ND	DIGI-KEY	480			0.305	146
4	640	BAY99	BAY99DICT-ND	DIGI-KEY	640			0.208	133
3	480	ES2DA	ES2DADICT-ND	DIGI-KEY	480			0.456	219
8	1280	DO214AB	1.5SMC540A	VISHAY	1280			0.301	395
4	640	60D100B	APT60D100B	APT	640			2.340	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	SWITCHEVQ	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
1	160	XCR3032XL		XILINX	160			2.100	336
1	160	CSX750PBC	CSX750PBC-ND	DIGI-KEY	160			2.970	475
0	0	HCPL2611	HCPL2611V-ND	DIGI-KEY	0			0.567	0
0	0	NTA1215	C&D	800-543-8630	0			2.700	0
3	480	QIS450602	QIS4506001	POWEREX	480			83.250	39960

## MECHANICAL

1	160	PCB, SWITCH30		COLO CKTS	160			25.000	4000
0.333	53.28	AL HEATSINK EXTRU 60140		AAVID	53			15.000	799
1	160	MACHINED HEATSINK SWITCH30		SMPCO	160			30.000	4800
2	320	HEATSINK PADS 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 MODULE 382.2**

**IGBT MODULE M&S, TOTAL MODULATOR 61158.2**

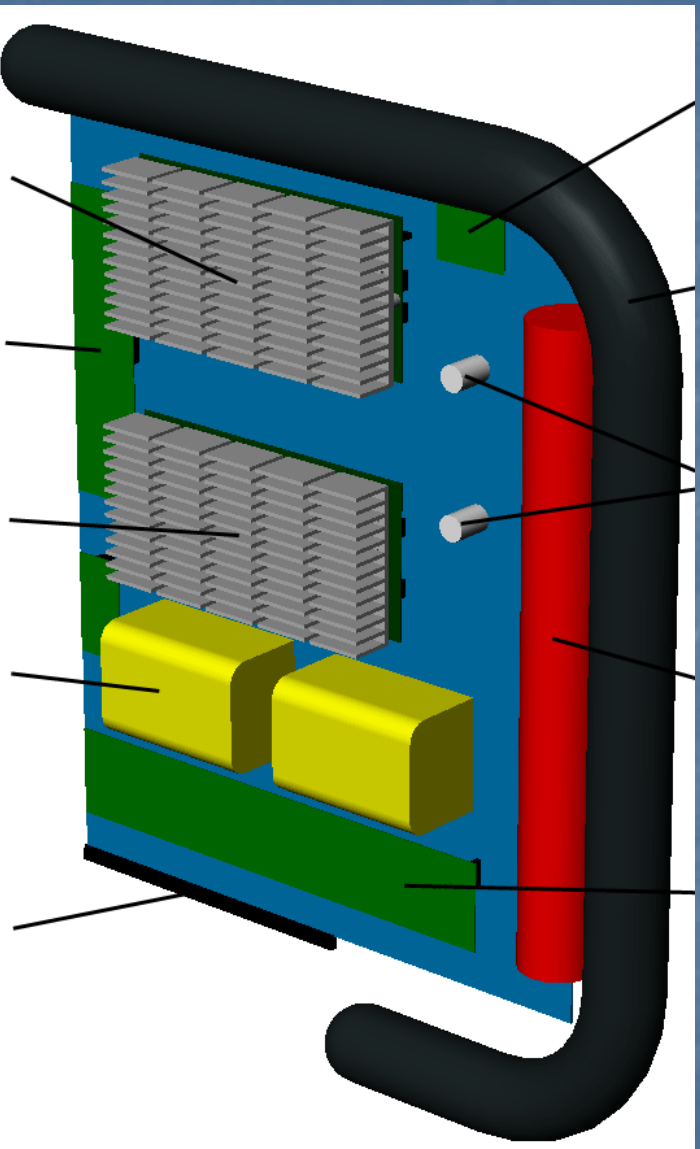
## LABOR, MODULE ASSEMBLY AND TESTING

	PROCEDURE	TIME, hr/unit	\$/hr	UNIT \$	ORDER \$
	SURFACE-MOUNT PLACEMENT	0.10	25	2.50	400
	THROUGH-HOLE PLACEMENT	0.20	25	5.00	800
	MECHANICAL ASSEMBLY	0.25	25	6.25	1000
	MODULE TESTING AND CALIBRATION	0.15	25	3.75	600

**LABOR, PER MODULE 17.5**

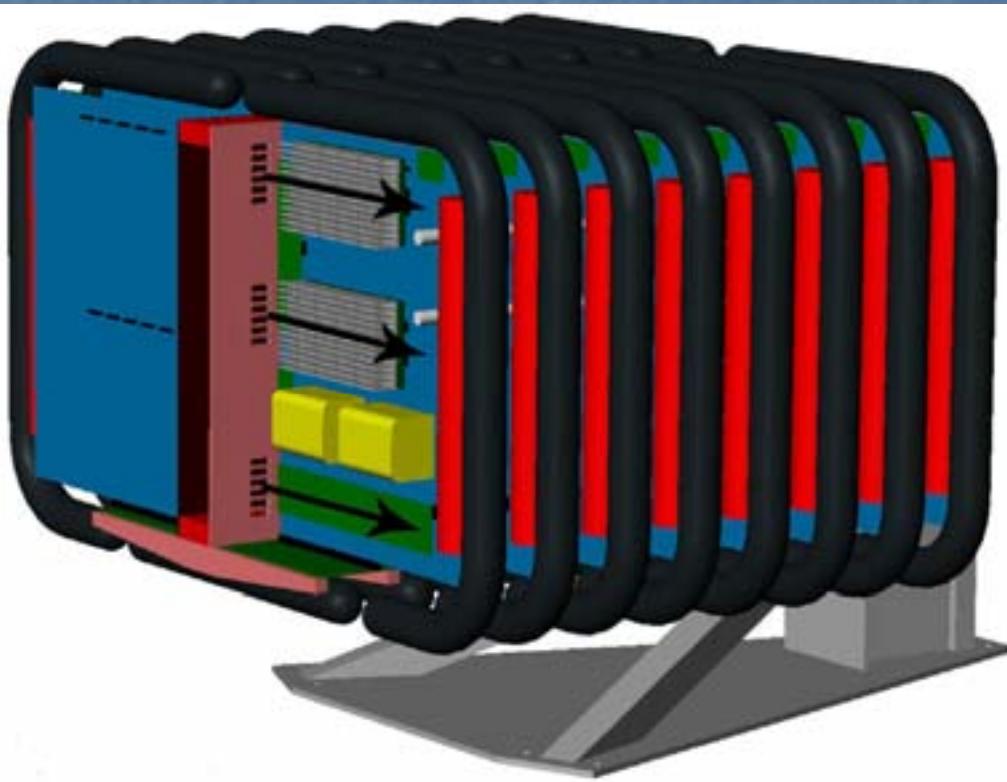
**IGBT MODULE LABOR, TOTAL MODULATOR 2800**

# Costing – Marx Cell Level

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# Costing – Marx Modulator Top Level



## BOM, MODULATOR TOP LEVEL

### MARX CELL STACK

				\$/MOD	
FROM IGBT MODULES TOTAL M&S				61158	
FROM DIODE AND CONTROL MODULES TOTAL M&S				11247	
FROM CELL COMPONENTS TOTAL M&S				58311	
			<b>MARX CELL STACK M&amp;S</b>		<b>130716</b>

### VERNIER REGULATOR

DESCRIPTION	\$EA	#/CELL	16 #/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	
			<b>VERNIER REG M&amp;S</b>		<b>6348</b>

### 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	
			<b>SYSTEM LEVEL M&amp;S</b>		<b>36040</b>
			<b>MODULATOR TOTAL M&amp;S</b>		<b>173104</b>

## LABOR, MODULATOR TOP LEVEL

PROCEDURE		TIME	\$/hr	\$/MOD	
FROM IGBT MODULE LABOR				2800	
FROM DIODE AND CONTROL MODULE LABOR				840	
FROM CELL LABOR				760	
MECHANICAL INTEGRATION, STRUCTURAL	25	25		625	
MECHANICAL INTEGRATION, ENCLOSURE	35	25		875	
MECHANICAL INTEGRATION, OTHER	60	25		1500	
TESTING AND CALIBRATION	15	35		525	
			<b>MODULATOR TOTAL LABOR</b>		<b>7925</b>

**MODULATOR TOTAL M&S + LABOR 181029**