High Precision power supply for accelerator magnets

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In an accelerator system high precision power supplies are used for generating highly stabilized magnetic field for performing various dynamic functions of the charged particles with high accuracy to obtain highly stable beam output as required for various experiments and studies.

Main feature of the power supply

Stability is the main feature of these power supplies which lies between ± 5 ppm to ± 100 ppm i.e. the output current will have to remain in the error band of ± 5 ppm to ± 100 ppm under various environmental perturbations such as :

- The input AC lines may ramp or step ± 10%.
- The magnet resistance may vary by 20%
- The ambient temperature could change from 15□C to 45□C
- There are AC line harmonics and notches generated by other power supplies.
- The power supplies themselves generate a fundamental 600Hz rectifier ripple and some harmonics of 50Hz due to line imbalances.

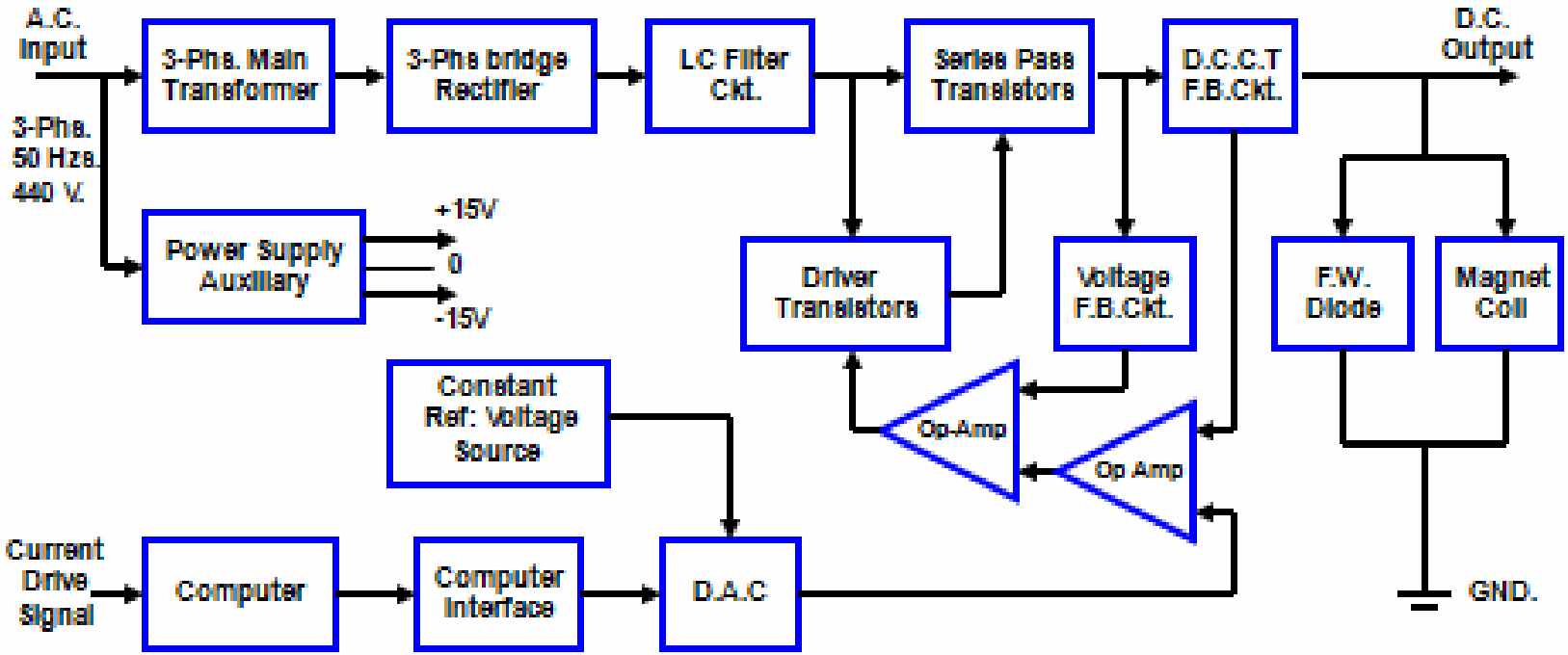
Stability of high precision power supplies in VECC room temperature cyclotron system

High Precision power supply	Typ. Rating (DC)		Stability	Application
	A	V		
Main Magnet P.S.	3000	150	5 ppm	Acceleration of charge particle
Analyzing Magnet P.S.	500	150	5 ppm	Beam resolution
Trim Coil P.S.	2500	25	10 ppm	Trimming of main magnetic field
Switching Magnet P.S.	300	150	10 ppm	Switching of beam to expt. channel
Quadrupole Magnet P.S.	300	30	100 ppm	Focusing of beam
Stearing Magnet P.S.	10	100	100 ppm	Stearing of beam inside the channel
Valley Coil P.S.	300	30	100 ppm	Centering of beam orbit

Action to achieve high stability of power supply

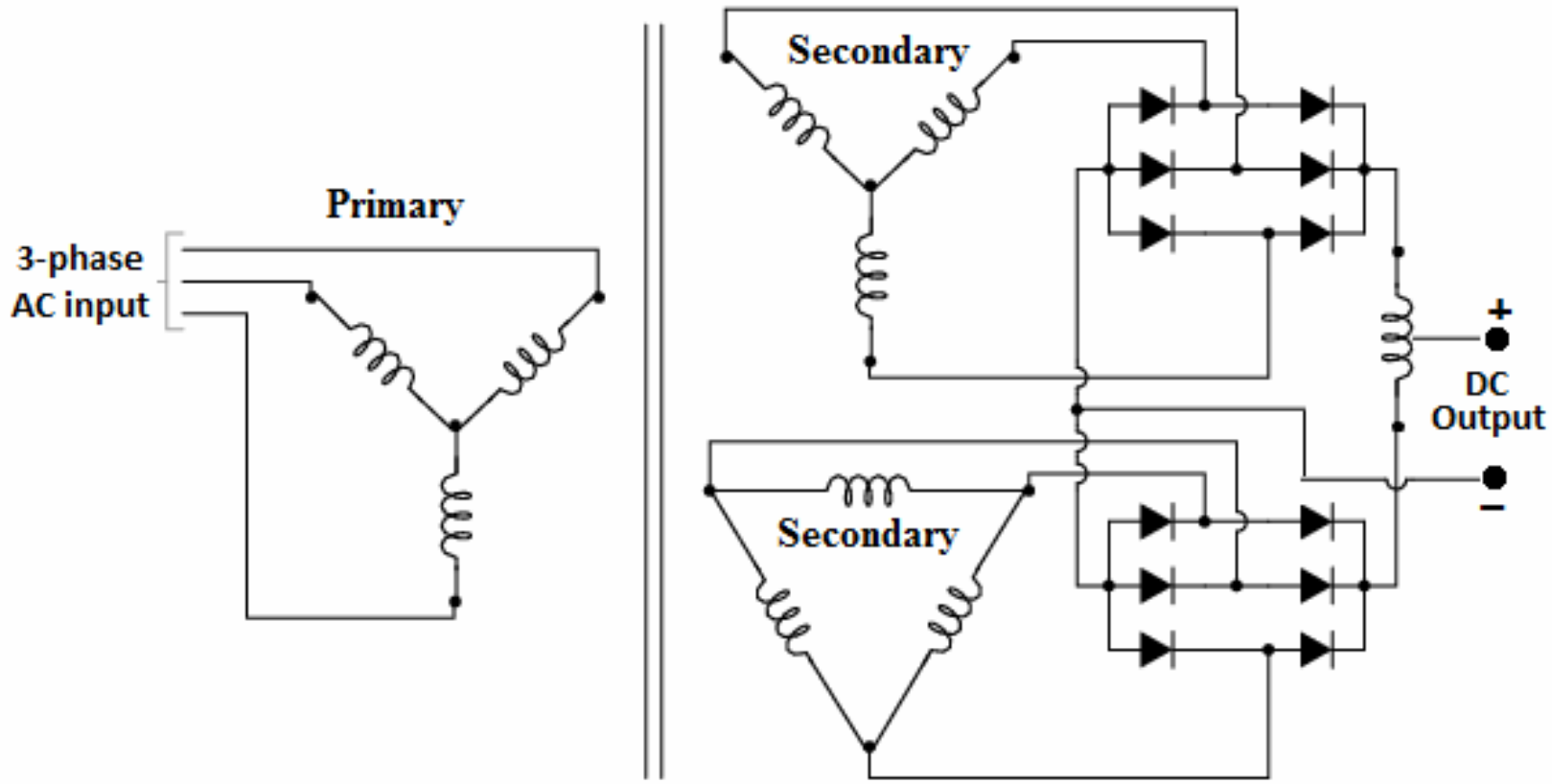
- Proper selection of rectifier circuit configuration for high ripple frequency to reduce ripple voltage
- Use of both passive and active filters for fine reduction of ripple voltage
- Adaptation of proper regulating loops for good voltage and load regulation
- Use of DCCT working on zero flux principle for sensing load current with 0.001% accuracy for high current regulation and stability
- Proper thermal management to control temperature of the heat dissipating devices and critical components of the power supply to minimize drift in characteristics due to temperature variation.
- Attenuation of R.F. pick-up and noise
- Taking proper action to reduce line disturbances

Block diagram of a high precision power supply for accelerator magnet



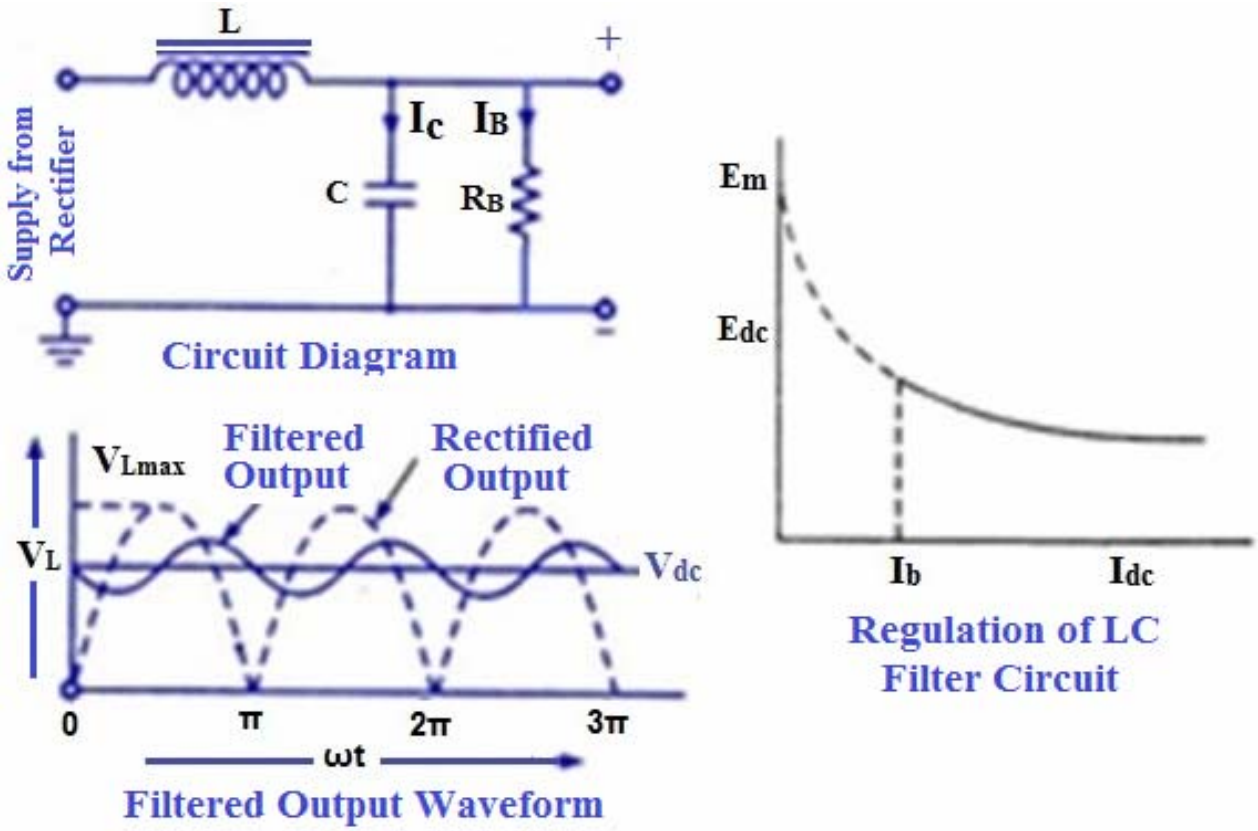
Series pass transistor controlled linear mode circuit configuration is adopted for simplicity in design and control for these power supplies.

Rectifier Circuit



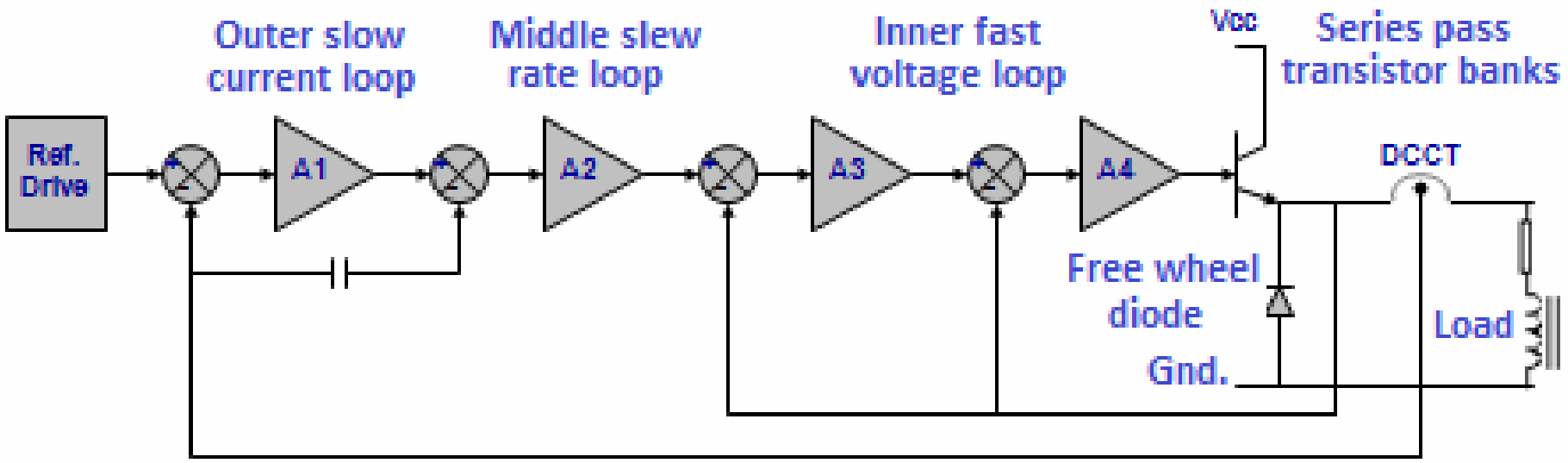
Considering the optimum rectification condition twelve pulse bridge rectifier circuit is adapted to achieve ripple voltage of 1.02%

L.C. Filter Circuit



The LC filter has almost constant ripple characteristics at all load current above I_B where the diode conduction angle reaches 180□ and the current becomes continuous. Because of the good voltage regulation at current above I_B, it is usual to operate the power supply with a bleeder resistor across the output.

Regulating Loops



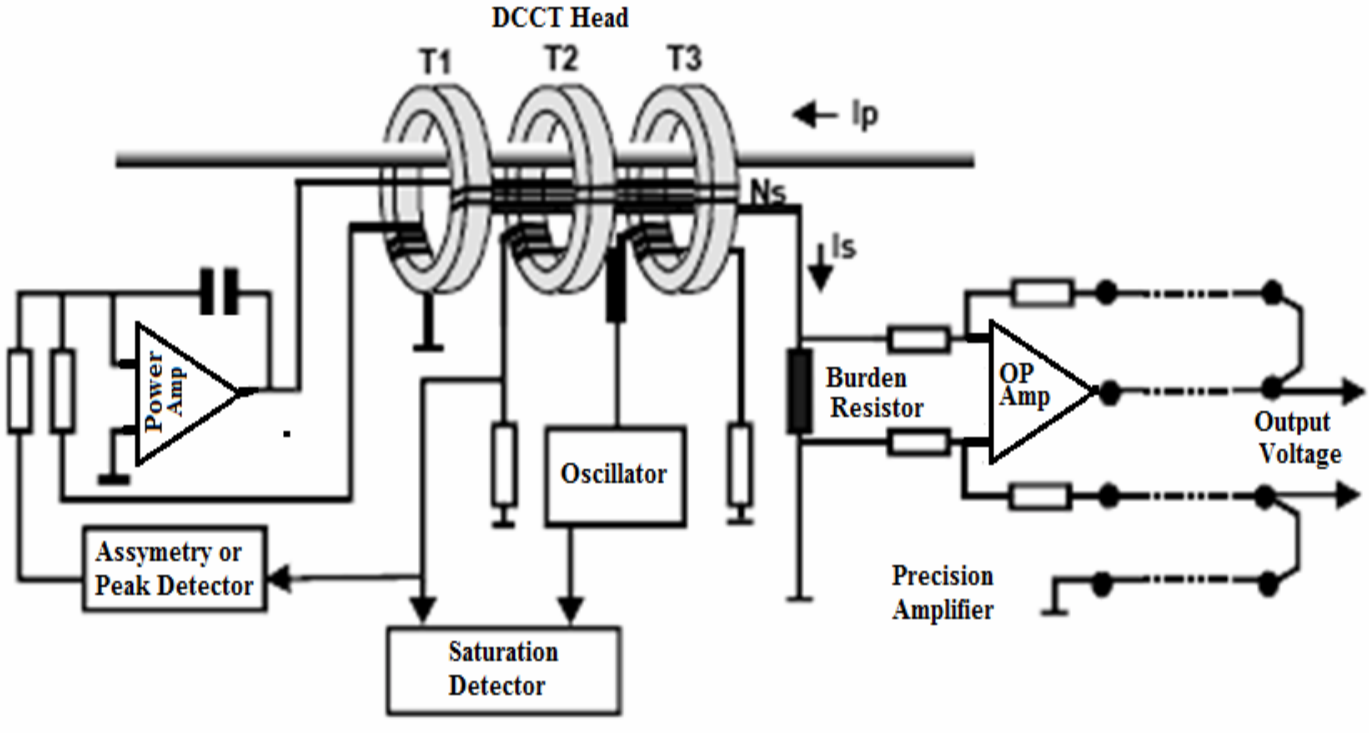
Three nos. regulating loops are used for high stability:

1. Inner Fast Voltage Loops: These attenuate the output voltage ripple and hum and the output voltage fluctuation due to main supply fluctuation.

2. Middle Slew Rate Loop: It ensures an excellent slew rate linearity independent of the load and set value.

3. Outer Slow Current Loop: It ensures the overall stability of the power supply.

High Precision Current sensor DCCT

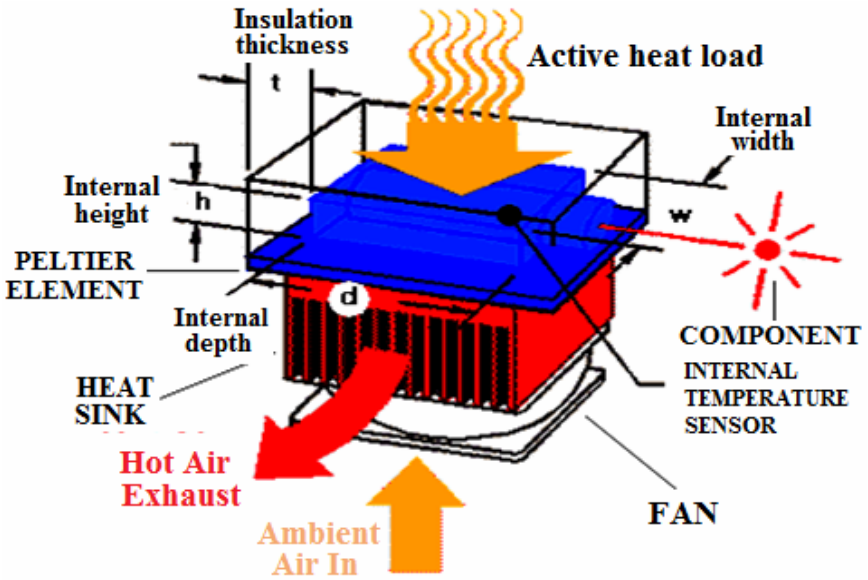


DCCT working on zero flux principal is used for sensing DC current with 0.001% accuracy. The electronic control circuitry is completely isolated from the main power circuit of the power supply and earth for reason of safety and stray current path which produces measurement error. The measuring head consisting of three identical toroids senses the residual field and controls the amplifier in such a way as to keep the net field zero.

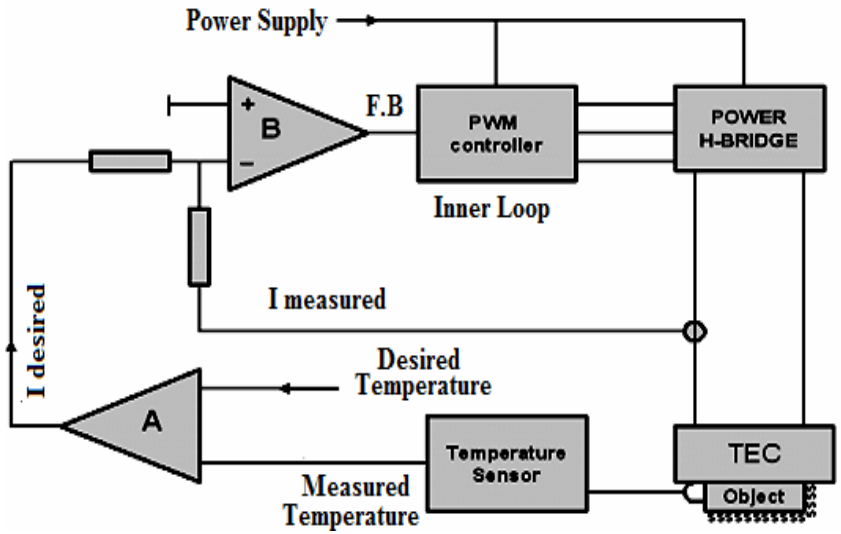
Thermal Management for power supply stability

***Peltier cooler and controller*:** These keep the operating temperature of the critical components such as error amplifier, DAC and burden resistance of DCCT enclosed in the peltier cooler, constant around 35ºC slightly above room temperature with 0.2ºC accuracy.

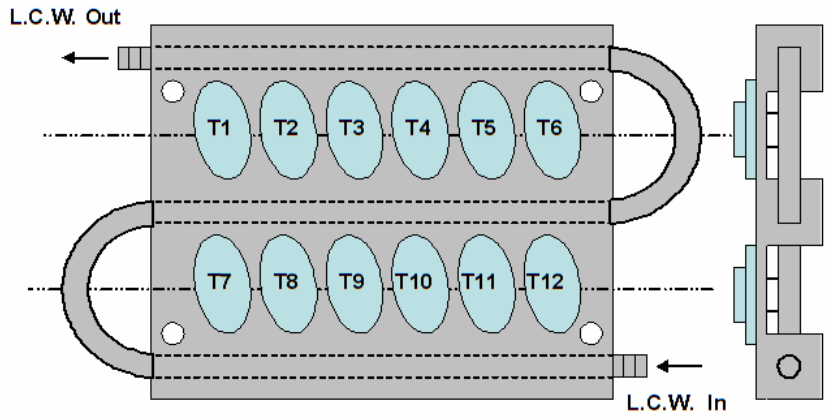
Peltier Cooler



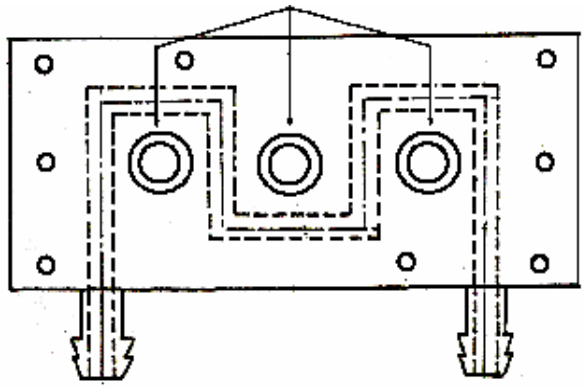
Peltier Controller



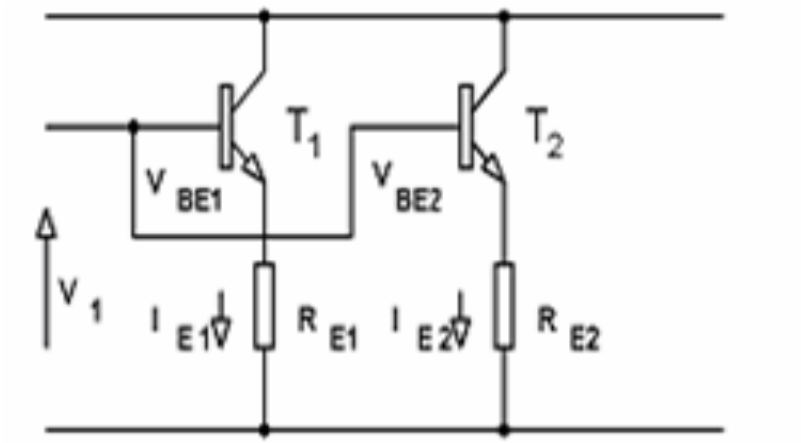
Low Conductivity water cooled heat sink: Efficient low conductivity water cooled heat sinks are used for cooling of power transistors and diodes, small balancing resistor is added to the emitter of each of the transistors in parallel for balance current sharing required for high stability of the power supply



Diode mounting hole



L.C.W cooled heat sinks for Transistors and diodes



$$V_1 = V_{BE1} + R_{E1} I_{E1} = V_{BE2} + R_{E2} I_{E2}$$

$$R_E = R_{E1} = R_{E2}$$

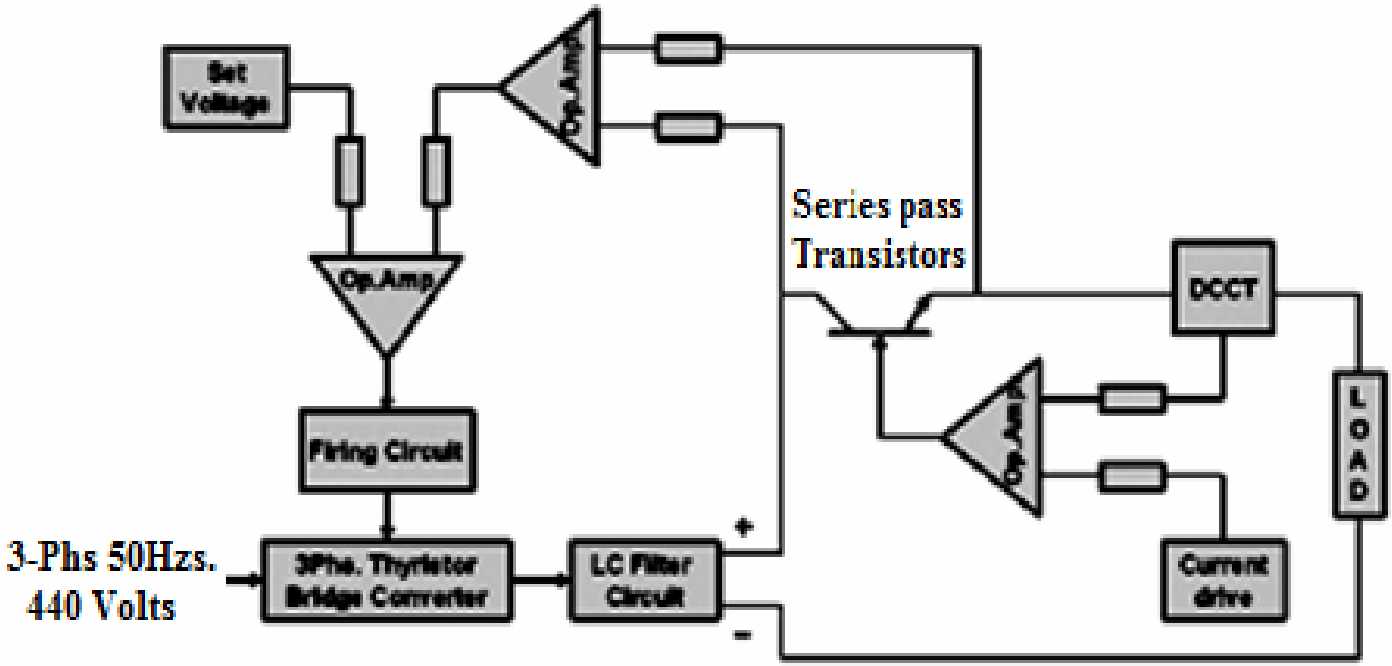
$$R_E = \frac{V_{BE2} - V_{BE1}}{I_{E1} - I_{E2}}$$

$$\left[I_{E1} = I_{C1} - I_{B1} \quad I_{E2} = I_{C2} - I_{B2} \right]$$

Calculation of current balancing resistor

Pre-regulator System :

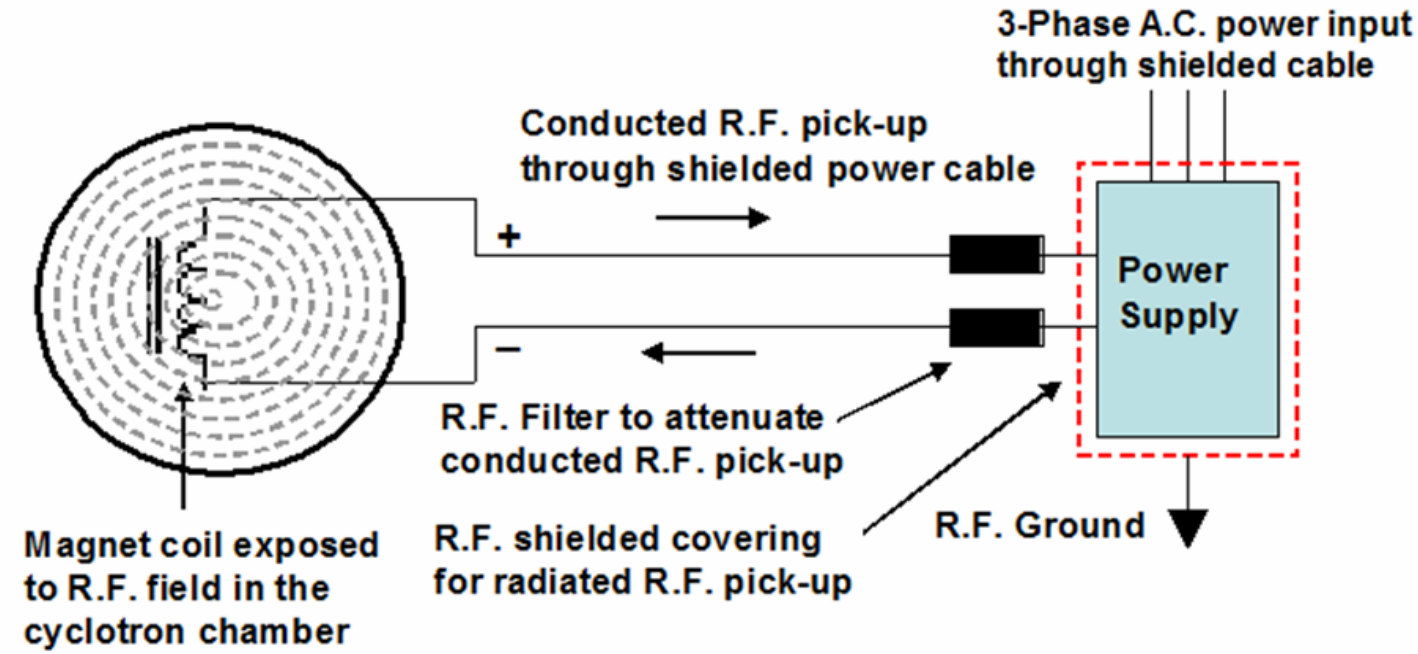
It is used to reduce power dissipation in the series pass transistor normally for Load current more than 1000 Amps.



Air conditioning of the power supply location environment:

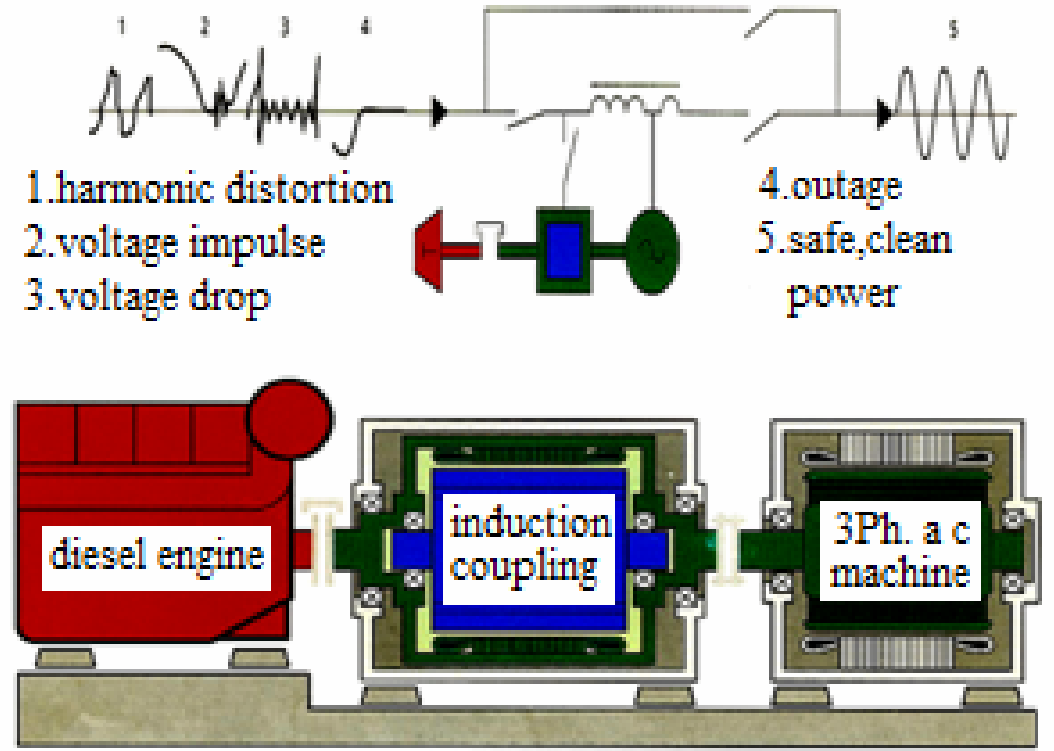
The temperature of the environment of the power supply location is kept around 25°C to 30°C by proper air conditioning for proper functioning of the power supplies.

Attenuation and Shielding of R.F. Pick-in the power supply



The conducted R.F. pick-up transmitted to power supply through power cable connected to magnets in the cyclotron chamber is attenuated with R.F. filter and the radiated pick-up radiated from the cyclotron chamber transmitted in the power supply is stopped by properly grounding and shielding of the power supply electronics modules and power supply cabinet.

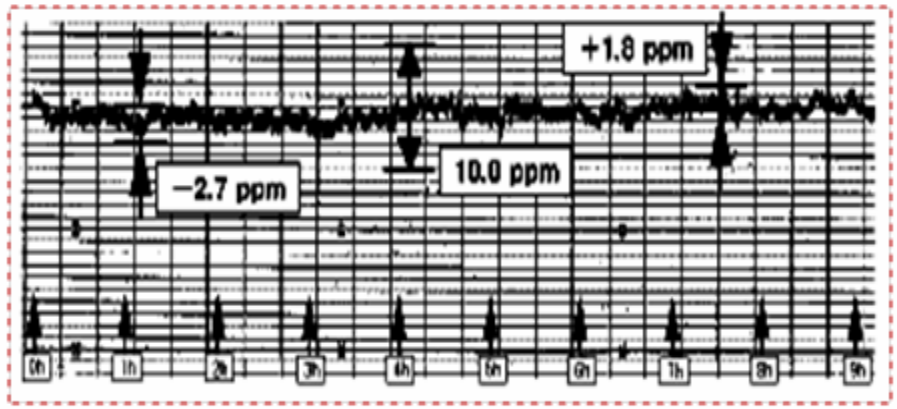
Line-interactive UPS System to overcome line disturbances



The induction coupling acts as a store of kinetic energy. It handles the line voltage dips and keeps the generator running before the diesel engine comes into action to run the generator when main power fails. The choke and the synchronous 3-phase a.c. machine together act as a stabilizing filter and provide clean regulated power from the mains during normal operation. The three phase a.c. machine acts as a synchronous motor when normal power exits. The diesel engine operates when normal power fails. Then the a.c machine acts as a generator.

Performance data of a 5ppm high precision power supply

Parameter	
Short term stability: (30min)	3ppm
Long term stability: (8hrs)	5ppm
Line regulation: Ramp or step within ±10% of supply line	0.5ppm
Load regulation: Magnet coil resistance change within ±10%	0.5ppm
Temperature coefficient: (per ^{0}C) •Ambient temperature variation at P.S. location in the range of 20°C to 30°C •Cooling water temperature variation in the range of 20°C to 35°C	0.2ppm 0.05ppm
Ripple: Current ripple in magnet	0.15ppm



Stability graph of a high precision power supply

The stability is calculated to be +1.8ppm – (-2.7ppm) = 4.5ppm.

Thank you

Спасибо