PIP-II MTBF Calculation for PIP-II Solid State Power Amplifiers

Engineering Note

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Document Approval

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# Purpose

The purpose of this document is to describe the calculation used to determine the mean time between failure (MTBF) of the PIP-II linac RF amplifiers. This calculation will be used to estimate the frequency that the RF amplifiers will require maintenance during operations and its impact on the overall linac reliability.

# Acronyms

|  |  |
| --- | --- |
| List acronyms here |  |
| HB650 | High Beta 650 MHz Cryomodule |
| HWR | Half Wave Resonator |
| LB650 | Low Beta 650 MHz Cryomodule |
| MTBF | Mean Time Between Failure |
| RF | Radio Frequency |
| RFQ | Radio Frequency Quadrupole |
| PIP-II | Proton Improvement Plan II Project |
| SSR | Single Spoke Resonator |
|  |  |

# Reference Documents

|  |  |  |
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| **#** | **Reference** | **Document #** |
| 1 | List references here |  |
| 2 |  |  |
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# Scope

The scope of this calculation encompasses the aggregate of all of the high power amplifiers used in the PIP-II linac.

# Basis of Estimate for Module Failure

The Fermilab synchrotrons utilize high power, vacuum tube amplifier systems to accelerate beam. These amplifier systems include solid state amplifiers that drive the grid or collector of the tube, depending on the configuration. Spread about the Fermilab Booster, Main Injector, and Recycler are 272, 1kW solid state driver amplifiers that are maintained by the AD/RF department. The department keeps failure and repair records on all the driver amplifiers, and they average about 1 repairable failure per year. This gives a MTBF of the 1kW amplifiers of about 272 years.

Since each 1kW driver amplifier has a dedicated DC power supply, the MTBF estimate includes failures of amplifier transistor modules and their respective power supplies. In the larger amplifiers used for PIP-II, a single DC power supply can drive multiple amplifier transistor units. This calculation does not distinguish the separate failure of DC power supplies from the modules but uses the more conservative assumption that the modules and power supplies will fail as a unit

# Quantity of Modules

The PIP-II solid state amplifiers are designed to be modular. To create the peak power at the output requires the power combination of many smaller amplifiers internal to the amplifier. Table 6-1 shows the list of amplifiers specified for the PIP-II linac design with the number and power level of each module associated with the amplifier.

Table 6‑1: PIP-II RF System MTBF Estimate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| SystemName | Output power | number of amplifiers | module power | modules/ Amplifier | System MTBF (years) |
| RFQ | 75 kW | 2 | 5 kW | 16 | 8.50 |
| Buncher (HWR 3 kW) | 3 kW | 5 | 3 kW | 1 | 54.40 |
| HWR | 7 kW | 8 | 1 kW | 8 | 4.25 |
| ssr1 | 7 kW | 16 | 1 kW | 8 | 2.13 |
| ssr2\* | 20 kW | 35 | 1 kW | 24 | 0.32 |
| LB650 | 40 kW | 33 | 2 kW | 26 | 0.32 |
| HB650\* | 70 kW | 24 | 2 kW | 52 | 0.22 |

\* Amplifier design is not finalized. These are extrapolations.

The MTBF for each amplifier system is calculated by dividing the MTBF for a single 1kW module and dividing by the total number of modules in the amplifier system. This assumes that each module has the same MTBF regardless of power rating. The total MTBF calculated for all the amplifiers is about 31 days. This implies that if all amplifier modules failed in a randomly distributed order, we would be replacing a module a month on average. This should be sufficient reliability for PIP-II beam operations.

# Annual Spares Consumption

Table 7-1 shows the results of calculating the expected number of spare modules consumed over the course of a year. The table shows the average number spares consumed annually, based on the MTBF. It also shows the number of spares consumed within an 80% confidence level, based on a normal distribution of failure probabilities. This value is used as a reference to determine the numbers of spares to keep on hand to maintain operations over the course of a year.

Table 7‑1: PIP-II RF System Spares Consumption

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| SystemName | Output power | number of amplifiers | modules/ Amplifier | Yearly Expected Replacements 50% confidence | Yearly Expected Replacements 80% confidence |
| RFQ | 75 kW | 2 | 16 | 0.1 | 0.4 |
| Buncher (HWR 3 kW) | 3 kW | 5 | 1 | 0.02 | 0.1 |
| HWR | 7 kW | 8 | 8 | 0.2 | 0.6 |
| ssr1 | 7 kW | 16 | 8 | 0.5 | 1.1 |
| ssr2\* | 20 kW | 35 | 24 | 3.1 | 4.6 |
| LB650 | 40 kW | 33 | 26 | 3.4 | 5.0 |
| HB650\* | 70 kW | 24 | 52 | 4.6 | 6.4 |