Linear Collider Collaboration Tech Notes

NLC Reliability Analysis Notes: Klystron-Modulator System

November 15, 1999

Zane Wilson
Stanford Linear Accelerator Center
Stanford, CA, USA

Abstract:
This paper address the reliability and availability issues to be faced in deploying and operating the klystron-modulator assemblies proposed for the Next Linear Collider (NLC). The rf power sources are a major system of the NLC and require a high uptime in order to reach the goal of 0.85 availability. Since the NLC is made up of several systems, not just klystron-modulator assemblies, the availability goal for the assemblies must be higher than 0.85. Currently this goal is at least 0.95. This short paper summarizes the analysis currently under way to determine whether the design of the rf power system will meet the design availability goal.

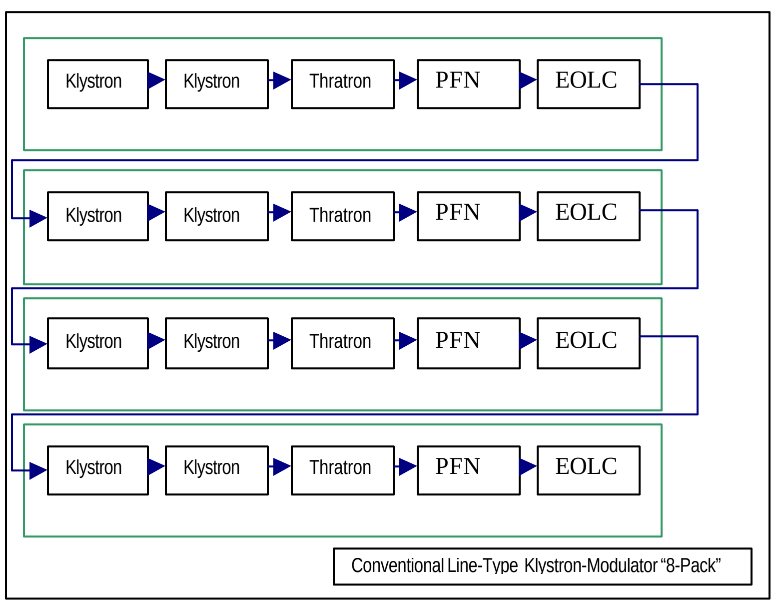
NLC Reliability Analysis Notes:
Klystron-Modulator System

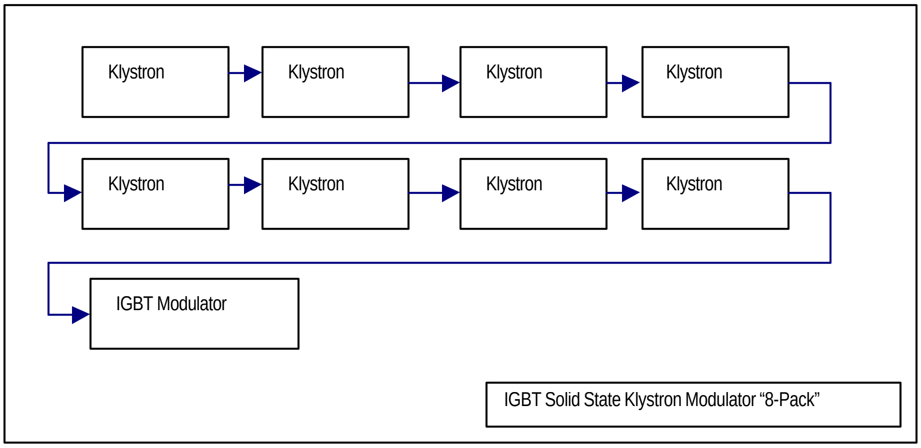
By: Zane Wilson , Stanford Linear Accelerator Center, Stanford University
US Department of Energy

This paper addresses the reliability and availability issues facing the deployment and operation of the klystron-modulator assemblies proposed for the Next Linear Collider (NLC). The rf power sources are a major system of the NLC and require a high uptime in order to reach the goal of 0.85 availability. Since the NLC is made up several systems in addition to klystron-modulator assemblies the availability goal for the assemblies must be higher than 0.85. Currently this goal is at least 0.95. This short paper summarizes the analysis currently being conducted to see if the design of the system will meet the design availability goal. It deals primarily with the issue of using a solid-state modulator to drive 8 klystrons (or 4 pairs). This configuration is known as the Solid State 8-pack. The analysis was done using the following models/tools:

1. A review of the klystron-modulator design that will be used to develop a reliability block diagram (RBD). The components were grouped in the 8-pack configuration for analysis.
2. Since availability is the driving factor for the accelerator a Logistic Support Analysis Report (LSAR). was generated. This report will allow us to see the operational effects on the klystron availability.
3. Knowing the LSAR and other parameters a discrete time model was created using the software packages Extend and MathCAD. The results of this model and the availability numbers generated will be shown.

The solid state klystron-modulator assembly used in the analysis is based on the design by Dick Cassel and company. The model of the system is made up of: eight 75-MW klystrons and one modulator power supply using a solid state switch known as an IGBT. This model differs from the other proposed system, a traditional line-type modulator. The conventional klystron-modulator system was our starting point and impacted the way the modeling of the solid-state modulator was done. In order to show this impact we will outline the conventional system. The conventional system model consisted of five major components that contribute most to the reliability of the system. They are: Two 75-MW klystrons, a thyratron, apulse forming network (PFN), and an end of line clipper (EOLC). As you can see, the number of klystrons is different from the solid state system and the reason for that is the tubes are put in pairs on the assembly and then four pairs are joined together. The differences are also evident in the RBD's of each system shown below:





Each of the components for the proposed systems was then assigned a projected mean time between failure (MTBF) to be used for the model. The mission time, the time the components are expected to operate

Mission time in hours (t)

$t := 365.25 \cdot 24 \cdot .75 \quad t = 6574.5$ hrs.

Tube (2) MTBF	Thyratron MTBF	PFN MTBF	EOLC MTBF
$MTBF_{trans} := 20000hr$	$MTBF_{thy} := 20000hr$	$MTBF_{PFN} := 100000hr$	$MTBF_{EOLC} := 150000hr$
$\lambda_0 := \left(\frac{1}{MTBF_{trans}}\right) \cdot 2$	$\lambda_1 := \frac{1}{MTBF_{thy}}$	$\lambda_2 := \frac{1}{MTBF_{PFN}}$	$\lambda_3 := \frac{1}{MTBF_{EOLC}}$

$\sum \lambda = 1.667 \times 10^{-4} hr^{-1}$

$n := length(\lambda)$

$i := 0..n-1$

$MTBF := \frac{1}{\sum_i \lambda_i}$ hours (MTBF for 1 Conventional X-Band Klystron Modulator Assembly)

$MTBF = 6000hr$

without failure, was set to 9 months. The MTBFs for each component are shown next.

The MTBF of 6000 hours shown is for one pair a “2-pack” of the conventional system. For an “8-pack” of the conventional system the MTBF would be:

$\lambda_{8pack} := 4 \cdot \lambda_{xband} \qquad \lambda_{8pack} = 6.667 \times 10^{-4} hr^{-1}$

$MTBF_{8pack} := \frac{1}{\lambda_{8pack}} \qquad MTBF_{8pack} = 1.5 \times 10^{3} hr$

Now for the solid state IGBT modulator we believe that the inherent reliability of the system should be much greater than the conventional one. For the sake of the model we made it over 15 times better. This was done for another reason as well. There was some concern that the combining of one modulator with 8 klystrons would cause the availability to be unacceptable. From the RBDs above you can see this clearly. The loss of the modulator in the solid state case would take 8 klystrons off-line. The loss of one of the modulators in the conventional case however, would only put two klystrons down. It is believed that the increased reliability of the solid state modulator will make up for this and so the assumptions shown below were made for the solid state IGBT system:

Tube (8) MTBF   IGBT/Modulator System MTBF

$MTBF_{trans} := 20000 hr$ $MTBF_{igbt} := 250000 hr$

$\lambda_0 := \left(\frac{1}{MTBF_{trans}}\right) \cdot 8$ $\lambda_1 := \frac{1}{MTBF_{igbt}}$

$\sum \lambda = 4.207 \times 10^{-4}\, hr^{-1}$ $n := length(\lambda)$

$i := 0..\, n - 1$

$MTBF_{igbt} := \frac{1}{\sum_i \lambda_i}$ hours (MTBF for 1 X-Band Solid State Klystron Modulator Assemb

$MTBF_{igbt} = 2377.179 hr$

It is important at this point to define what availability is. We have defined availability to be the MTBF divided by the sum of the MTBF and MDT.

$Availability := \frac{MTBF}{MTBF + MDT}$ MTBF = Mean Time Between Failur
MTD = Mean Down Time

or

$Availability := \frac{\mu}{\mu + \lambda}$ In this equation μ = Recover Rate
λ = Failure Rate

This Mean Down Time term is what we will discuss next. It is important to understand that reliability is something that is inherent to a device or system. The only way to improve reliability is by changing the design. Availability is what we experience most of the time and is impacted by how long it takes to fix the thing that is broken. It is very easy to see that if we do not repair the klystron-modulator assemblies all 414 of the required systems will not live to the end of the mission. MDT can be defined as the expected time for a response from the logistic support system. Put simply, it is how long it takes for a system to go from being down to the point were it is back up an operational. This number can be broken down to find how the time is being used and where improvements can be made. This analysis also allows you to calculate the load on your logistics system. Let us now generate an LSAR for the solid state system which we will use in our discrete simulation starting with the MDT term.

$P_{os} := .9$ Possiblity of repair accomplished at failure point. In this case the LRU (line replaceable unit) is the klystron can be removed and replaced.

$P_{sos} := .9$ Probability that the spare parts are on-site.

$MTTR_{os} := 17.5\,hr$ MTTR for failure point repair. In this case time to change out the LRU also includes a settling time for the oil.

$MADM_{os} := .5\,hr$ Adminstrative down-time on site. (including time to obtain spare parts from on-site storage.

$RESUP := 8\,hr$ Time to obtain longest lead-time part from off-site source.

$TAT_{off} := 48\,hr$ Turnaround time to have the product shipped and repair at off failure point facility.

$$MDT := \left[P_{os} \cdot \left[P_{sos} \cdot \left(MTTR_{os} + MADM_{os}\right) + \left(1 - P_{sos}\right) \cdot \left(MTTR_{os} + MADM_{os} + RESUP\right) \right] + \left(1 - P_{os}\right) \cdot TAT_{off} \right]$$

$MDT = 21.72\,hr$

The expected demand can also be stated as a function of the product's failure or maintenance action rate and the MDT. This demand number DEMin will tell you how many spares a system might need.

$MAR_{igbt} := \frac{1}{2377}$ Maintenance Action Rate, in this case I'm using the system failure rate as the removal rate.

$N_{lIGBT} := 828$ Number of systems that need to be up (1 TeV).

$N_{500IGBT} := 414$ Number of systems that need to be up (500 TeV).

$UTIL := 24$ Utilization, number of operational hours per day

$mdt = 21.72\,hr$

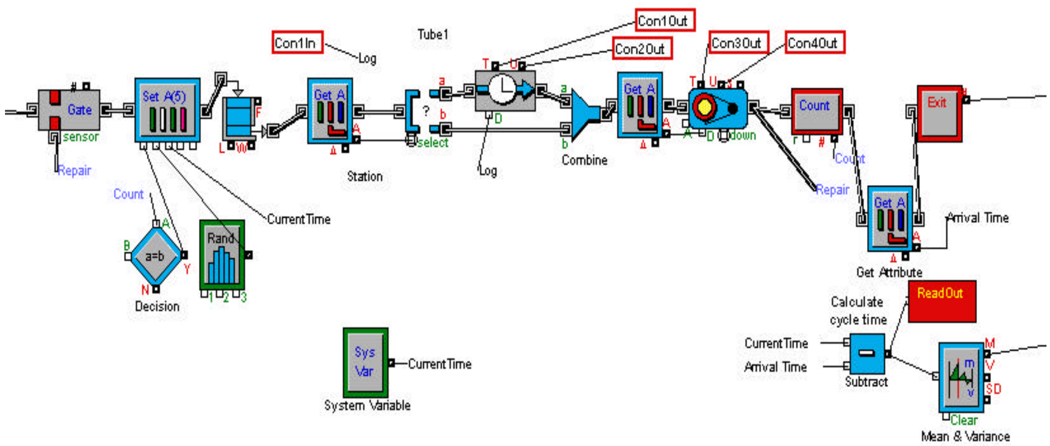
$MDT := mdt$ Mean down time in hours

$DEM := MAR \cdot N_{lIGBT} \cdot UTIL \cdot MDT$ $DEM = 86.324\,hr$ $DEM := MAR \cdot N_{500IGBT} \cdot UTIL \cdot MDT$ $DEM = 43.162\,hr$

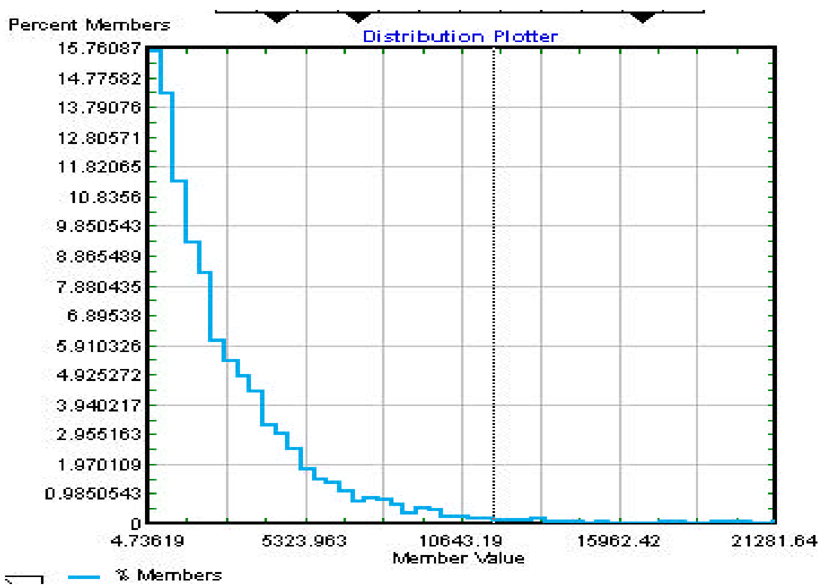
$DEMi := 86.324$ $DEM500i := 43.162$

We now have all the terms needed to simulate an availability model for the solid state IGBT system save one. The design of the main linacs currently includes a 3% overhead. This means that not all 414 systems need to be operating but 402 need to be working for the main linacs to be considered up. This is how the simulation was modeled.

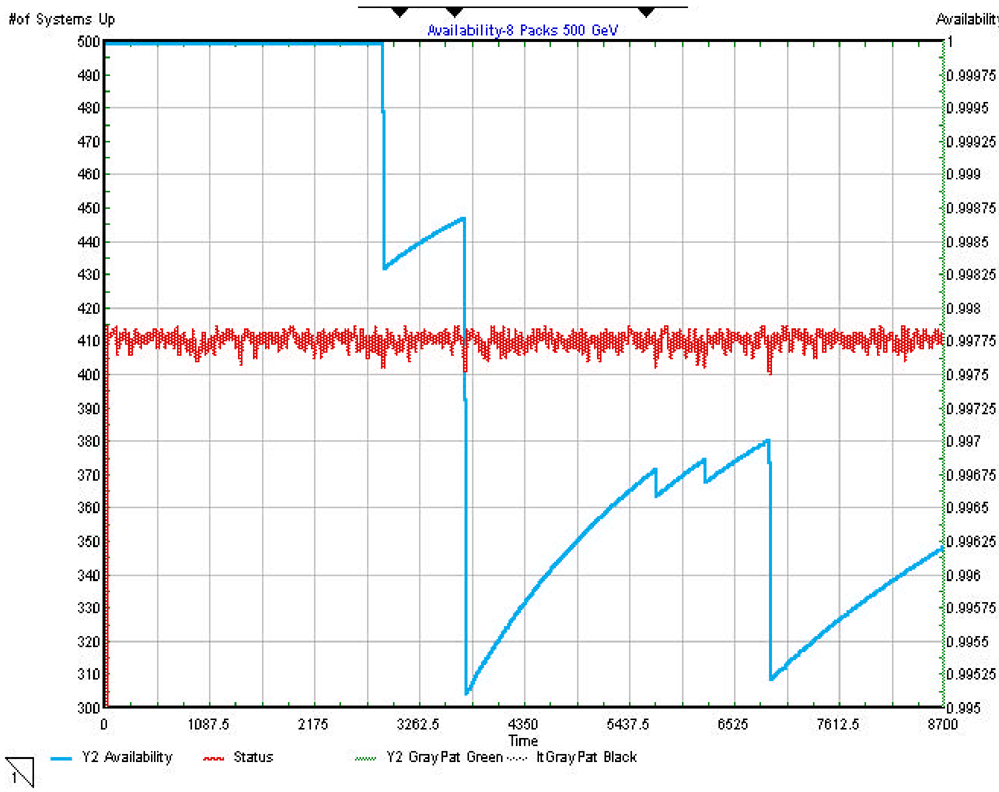
The simulation was built by creating first just one system. The 8 pack was put together as shown in the picture below. This is an actual screenshot from the simulation program.



This layout will simulate the actions that occur at one "8-pack" station including installation, use, failure and removal. The failure rate of the klystron is random based on the following Poisson distribution.

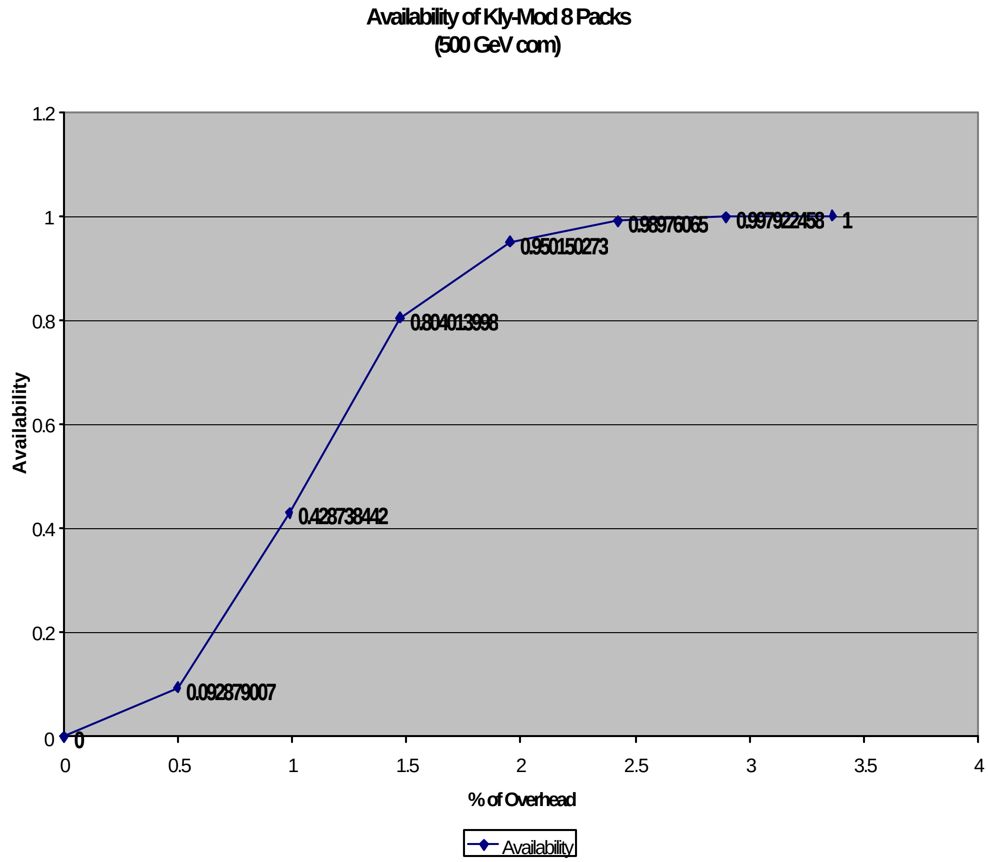


The "8-packs" above are then built up into sectors made up of nine "8-packs". There are 46 sectors in the current design of the NLC main linacs so the number of sectors in the simulation is also 46. It is important to note that the "8-packs" are a simplified model of the true modulator and as that design matures so will this simulation. The simulation was then run using the component lifetimes and MDT as stated. One the outputs created is a condition monitor of the main linac. In the same way a heart monitor tells the heart condition of a person the condition monitor shows the life of the main linacs. The monitor also tells us the availability of the linac during the mission. A simulation run is shown below:



The red dotted line in the center of the graph shows the number of systems up or status of the main linacs. The blue solid line shows instantaneous availability throughout the mission. As the graph shows the solid state systems have a high availability of around 0.996. This number easily meets our goal. A word of caution however. It is important to remember that the model reflects an immature design and that as more is known the availability will most likely go down. This decrease should not be extreme and the high modeled number gives some degree of confidence that the design can meet the goal.

A couple last notes, the sensitivity to amount of over head was also analyzed using the same model and those results are shown below. Also the 1 TeV com results should be a little better.



The work on the simulation is by no means complete and will continue to be refined. Some of the next steps involve not only better numbers for the components but the sensitive of "8-pack" location (front of linac, end of linac) need to be addressed. It is believed that the tool is a good one and should allow us to address these concerns as they come up.

Zane Wilson 11/10/99
Wilson@slac.stanford.edu