

REDUNDANCY ANALYSIS OF SOLID-STATE AMPLIFIERS FOR CIADS ACCELERATOR *

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Abstract

The solid-state amplifier(SSA) will be applied in China Initial Accelerator Driven System (CiADS) accelerator. 20KW SSA is the basis of RF power systems. With considering power loss redundancy of the main amplifier(MA) is analyzed by building k/N reliability model for various redundancy. 26/30 redundancy is optimal for 20KW SSA in term of reliability.

INTRODUCTION

The solid-state amplifier has proved to be quite reliable as well as easy maintenance compared to tetrode and klystron, so it will satisfy high availability of CiADS accelerator. CiADS amplifiers have four types: 20KW, 40KW, 60KW and 80KW [1] and they are combined by 20KW SSA.

Redundancy of SSA is analyzed by the fault tree(FT) model in IFMIF [2]. However, power loss is not considered and causes a large effect for availability analysis.

With considering power loss, k/n RBD model of MA is built and MTBF of various redundancy is calculated in this paper.

THE PRICIPLE OF 20KW SSA

20KW SSA is composed by RF chain, central control, the cooling system and power assembly. There are many components, such as limiter, attenuator, RF switch, 1:6 splitter, pre-amplifier which has six 50W-SSA, 6:1 combiner, 1:22 splitter, the main amplifier that has twenty-two 1KW-SSA, 22:1 combiner and coupler in RF chain. As is shown in Figure 1. The cooling system includes cooling pipe, pump and flowmeter. Central control is combined by an industrial computer and monitoring circuits.

Low level radio frequency(LLRF) transmit a signal to limiter which discriminates range of amplitude. Attenuator can amplifying signal and RF switch controls signal output. Small power amplifys to 20KW through the pre-amplifier and MA. The data that coupler monitors the power is transmitted to central control which gives commands to every component. The cooling system cools large-power components and power assembly complishes 220V or 380V conversion.

* Work supported by Strategic Priority Research Program-Future Advanced Nuclear Fission Energy (Grant No. Y102070ADS)

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K/N RBD MODEL OF MA

Component Definition

Component definition is different between physical model and RBD model. 20KW SSA is composed by components such as input control, splitter, the pre-amplifier, combiner, equivalent splitter, 1KW SSA, equivalent combiner, the cooling system and central control in RBD model. Here concepts of equivalent splitter and combiner are put forward to solve redundancy analysis of MA. If one 1KW-SSA is wrong, 20KW SSA which has twenty-two 1KW-SSA can not output rated power. If MA has twenty-four 1KW-SSA, 20KW SSA can tolerate one 1KW-SSA is wrong. Styles of splitting and combining which are different for various redundancy are unified with concepts of equivalent splitter and combiner and it will not affect reliability analysis.

Redundancy Analysis of MA

Insertion loss of equivalent combiner and equivalent splitter is 0.4dB. If guaranteeing P_o of SSA output is 20 KW, P_m of the main amplifier must equal 21.93KW according to the equation(1).

$$10 * \lg(P_m/P_o) = 0.4 \quad (1)$$

(P_m-P_o) is insertion loss of equivalent combiner. If the power source outputs 20KW, MA at least needs twenty-two 1KW-SSA. This situation is no redundancy. Any amplifier which is fault can cause the fault of the power source. If applying more than 22 amplifiers, the power source could tolerate one or a few amplifiers which are fault. However, in this case inconsistency of amplitude and phase will bring about additional power loss. N represents the number of total amplifiers and n represents the most number of amplifiers that are wrong. And $k=N-n$. We can calculate P_m according to equation(2) and equation(3). P_i represents the power output of k amplifiers. Different redundancy is as followed table1.

$$P_i = P_o * (N/(N - n))^2 \quad (2)$$

$$10 * \lg(P_m/P_i) = 0.4 \quad (3)$$

In conclusion, 24 amplifiers can tolerate at most one which is fault. 26 amplifiers can tolerate at most two which are fault. 32 amplifiers can tolerate at most five which are fault. k/N RBD model of MA is as followed Figure 2.

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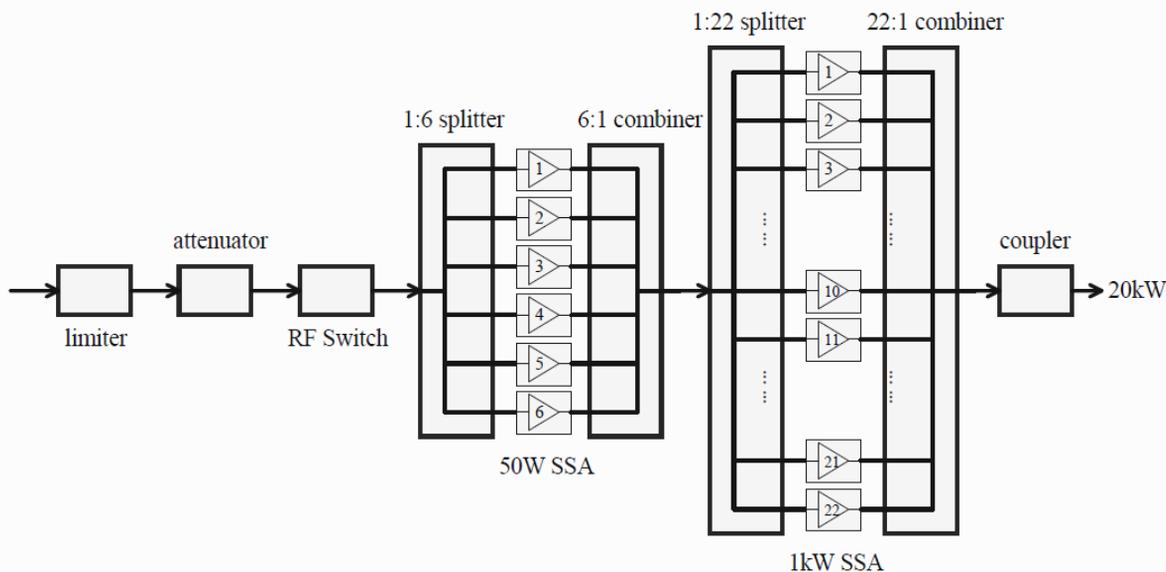


Figure 1: The schematic diagram of 20KW SSA.

Table 1: Various Redundancy of 20KW SSA

N	n	redundancy
22	0	22/22
24	1	23/24
26	2	24/26
28	3	25/28
30	4	26/30
32	5	27/32
33	6	27/33

The Weakness of 20KW SSA

MTBF of the system must be smaller than every component, so improving MTBF of the module which is high fault rate, reliability of the system increases more fast compared to the module that is low fault rate. According to running experience, 1KW SSA has the highest fault rate compared to other components. MA which is the weakness of 20KW SSA will apply degraded redundancy to improve MTBF of it. In general, MTBF of other components is longer than MTBF of MA.

Hypotheses and Assumptions

Using assumptions are as follows:

- (1) All components have only two states: fault and running.
- (2) The fault density of components obeys exponential distribution and Fault rate is reciprocal of MTBF. Every fault disables the component and it must be maintained.
- (3) There is no contact between components. The fault of one component can not cause non-function of other components.
- (4) MTBF of 1KW amplifiers is constant below rated power.
- (5) Definition of fault: components or systems do not accomplish desired function.

MTBF CALCULATION OF MA

The k/n reliability model of MA is built by Reliasoft. MTBF of 1KW SSA is 100000 hours in RBD model. MTBF of MA is calculate as Table 2. It is not difficult that MTBF of other components realises 200000 hours. Because other components can not reach 700000 hours, MA of 26/30 redundancy is not weakness of 20KW SSA. Considering cost and reliability, 27/32 or more redundancy is not taken account of.

Table 2: MTBF of MA in Various Redundancy

redundancy	MTBF(h)
22/22	4550
23/24	14924
24/26	49268
25/28	171702
26/30	700985
27/32	3052783
27/33	21052180

SUMMARY

26/30 redundancy is optimal for 20KW solid-state amplifiers. Because other components can not reach 700000 hours, MA of 26/30 redundancy is not weakness of 20KW SSA.

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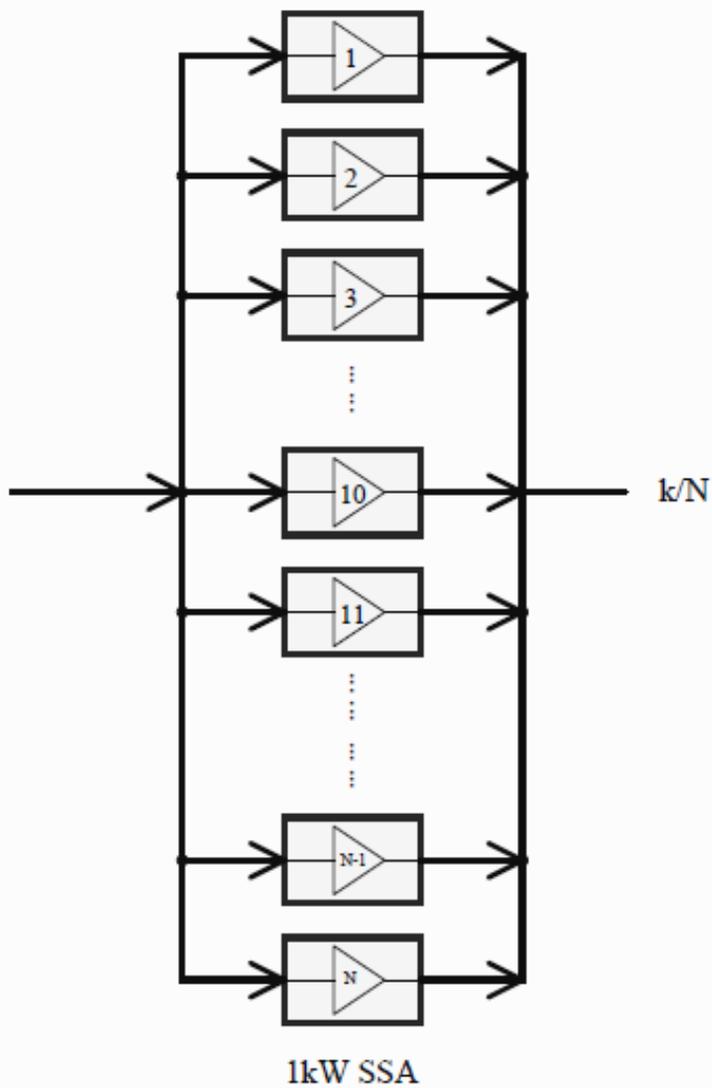


Figure 2: k/N RBD model of MA.