OPTIMIZATION OF REDUNDANT ANALYSIS AND DESIGN FOR SPACEWIRE

Session: SpaceWire Components

Short Paper

Yong GUAN, Guohui WANG

College of Information Engineering, Capital Normal University, Beijing, China

Jie ZHANG

College of Information Science & Technology, Beijing University of Chemical Technology, China

Shengzhen JIN, Yuanyuan SHANG, Huizhuo NIU

College of Information Engineering, Capital Normal University, Beijing, China

E-mail: gxy169@sina.com, wgh_boy@hotmail.com, zhang@mail.buct.edu.cn, jsz0622@163.com, syy@bao.ac.cn, ymdynhz@126.com

ABSTRACT

With limited resources available to acquire FPGA chips, a design method was developed based on the redundancy backup of the various functional sub-modules in SpaceWire node. The aims to find the optimization design of redundancy backup in an FPGA chip. This design method can improve the reliability of the whole system.

First, according to a failure rate of λ, the reliability of the control, transmitter, receiver, recovery, faulting, timing, reliability, and baud rate selection modules of the whole system was calculated, attaining a total of 0.8675. Second, to meet the reliability requirement of the whole system of the space-solar telescope for SpaceWire (0.95 after working in the 750 km sun-synchronous-orbit for three years), the reliability targets meeting the requirements of every module mentioned above were calculated and attained according to grading distribution. Finally, using the optimal solution based on linear programming in the theory which addressed the "optimal allocation of spare parts" problem, the optimization design of the redundancy backup of the various functional sub-modules was obtained. The simulation results proved the validity of this design, indicating that a new method in improving the reliability of the redundancy backup in the SpaceWire system has been developed.

1 INTRODUCTION

In meeting modern product quality requirements, reliability is of prominent importance. Backup program design and optimization is a basic work in reliability engineering. The SpaceWire designed should reach the target such that the reliability of the whole SpaceWire system is 0.95 after working in a 750 km sun-synchronous-orbit for three years. The initial design in FPGA has achieved a reliability of 0.8674, which is far from what was expected. However, in order to realize the SpaceWire node in an FPGA chip and perform scientific backup, high reliability requirements must be met, and the limited resources on the FPGA chip must be maximized. Therefore, a design is proposed which perform each functional sub-module within an FPGA-based Spacewire node redundancy backup, thereby enhancing the reliability of the entire system to meet task demands.

2 ALGORITHM OF THE BACKUP

2.1 RELIABILITY CALCULATION OF THE SUB-MODULE

With the development of EDA technology, the use of hardware description language design has become a trend. The SpaceWire node is achieved on a Xilinx's Spartan-3E (XC3S250E) FPGA, and the sub-module-level backup of the system is completed at the same time. To obtain the reliability of a sub-module before backup, the following are assumed: Ⅰ. A blank FPGA's reliability is 1. Ⅱ. The probability of Single Event Upset, electromagnetic interference, and other incidents is equal within the duration of three years. Ⅲ.The probability of damage in the working CLB of FPGA is the same. Ⅳ. The reliability of CLB which does not work is 1, and CLB is not damaged.

Let R_i be the reliability of the sub-module; let i=1,2,…,8. Let AP_i be the occupied area ratio for each sub-module; let i=1,2,…,8. If the occupied area ratio of the sub-module is small, then the effect is lesser, and the normal working hour is long. For the opposite condition, the effect is greater, and the normal working hour is short. The FPGA we used, whose CLB distribution is shown in Table 1. The number of CLBs occupied by each sub-module in the SpaceWire node is shown in Table 2. Let A_i be a factor of influence of the area, for i=1,2,…,8. Then the formula is

$$A_i=\frac{1}{AP_i} \tag{1}$$

Let t_0 express the normal working hour, then the Mean Time to Failure is

$$MTTF_i = A_i \times t_0 \tag{2}$$

The system failure rate for each sub-module is

$$MTTF_i = \int_0^{\infty} e^{-\lambda t}dt = 1/\lambda \tag{3}$$

Thus, the obtained formula for calculating the reliability of each sub-module is

$$R_i(t) = e^{-\lambda_i t_0} \tag{4}$$

Based on above Formulas (1), (2), (3), and (4), the reliability of the 8 sub-modules calculated is shown in Table 2. Then according to the series system reliability formula, the entire system reliability achieved is R = 0.8674.

Table 1: Spartan-3E FPGA Data Sheet[1]

IC	CLB		
	Row	Arrange	Total
XC3S250E	34	26	612

Table 2: The reliability of each sub-module

Sub-module	CLBs	Reliability
control module	12	0.9806
sending module	20	0.9678
receiver module	32	0.9491
recovery	12	0.9806
faulting module	2	0.9967
timing module	5	0.9919
credibility	2	0.9967
baud rate selection	2	0.9967

2.2 RATING DISTRIBUTION METHOD

The rating distribution method[2] is determined by peer experts based on the complexity, importance, and degree of difficulty to achieve the technology, among others. Evaluation is then made based on these factors, which not only reflects the characteristics of the whole system but also underlines the recommendations from the long-term accumulated experience of experts in technology. Finally, an effective backup program is given. The rate of each sub-module is given by experts according to the effect of the reliability of the system or the basic reliability of several key factors. Let K be the derived weighting factors for each sub-module, then the reliability is distributed.

Weighting the product depends on a variety of factors, including the characteristics of FPGA, as well as complexity, importance, hours of work, and technological factors. Such factors can be further divided into several levels. Generally, score is divided into five levels—*perfect, very good, quite good, good, and general*. According to the characteristics of the SpaceWire node, the experts present the results of the specific rates in Table 3.

Calculation of the reliability index for each sub-module:

Ⅰ. The weighing factors of the sub-module are

$$K_i = \frac{C_i}{C_s} \tag{5}$$

Ⅱ. The rating of sub-module is

$$C_i = \prod_{j=1}^{p} m_{ij} \tag{6}$$

Ⅲ.The rating of the system is

$$C_s = \sum_{i=1}^{n} C_i \tag{7}$$

Ⅳ. The sub-module reliability index is

$$\lambda_i = K_i \lambda_s \tag{8}$$

If the reliability index is R_s=0.95, then the system failure rate is λ_s=5.4217E-10 is calculated according to the formula ($R_s = e^{-\lambda_s t}$). The reliability distribution is completed depending on the formula ($R_i = e^{-\lambda_i t}$). The scores given by several experts in related fields are averaged, obtaining the result of each module by the formula (5), (6), and (7), as presented in Table 3. At the same time, the calculating of the specific circumstances of the reliability distribution through Formula (8) is also shown in Table 3.

Table 3: Index of each sub-module

Weighing factor	Complexity	Importance	working time	Technology	Rating of sub-module	Weighing factor	Failure rate	Reliability
control	3	2	2	5	60	0.0866	0.4694E-10	0.9956
sending	5	1	4	5	100	0.1443	0.7823E-10	0.9926
receiver	5	1	4	5	100	0.1443	0.7823E-10	0.9926
recovery	3	2	4	5	120	0.1732	0.9388E-10	0.9912
faulting	1	5	3	5	60	0.0866	0.4694E-10	0.9956
timing	1	5	5	4	125	0.1804	0.9779E-10	0.9908
credibility	1	4	4	5	80	0.1154	0.6259E-10	0.9941
baud rate selection	1	4	3	4	48	0.0693	0.3755E-10	0.9965
The Whole System					693	1	5.4217e-10	0.95

2.3 The Linear Programming Method

From Section 2.2, we learned that the rating distribution method is an effective backup plan, as pointed by the long-term technical background of experts. However, this method shares certain deficiencies like the subjective factor of experts, fuzzy weighted assignment and so on. The linear programming approach[3] is adopted. The relatively superior backup program can be discovered using the main factor for searching the most superior result. The scientific nature and validity of the allocation of the backup part are analytic, representing the complexity parameter aspect.

Let the system be composed of n inter-independent sub-modules. Every sub-module is realized by the same configurable logic block; let j=1，2，…，n,

C_j -- the area of sub-module ***j***.

K_j -- the number of sub-module ***j***.

$R_j(K_j)$--when the number of the ***j*** sub-module is K_j, the reliability of the sub-system ***j***.

Obviously, the reliability of the system is as follows:

$$R(k)=R(K_1, \ldots, K_n)=\prod_{j=1}^{n} R_j(K_j) \tag{9}$$

Let the system be composed of n inter-independent sub-modules. If the sub-module ***j*** is composed of K_j inter-independent modules ***j*** by parallel, let P_j for $j = 1,2, \ldots, n$ be the reliability of modules ***j*** , and the reliability of the modules ***j*** by parallel is as follows:

$$R_j(K_j) = 1 - (1 - P_j)^{K_j} \tag{10}$$

Here, the reliability of the system is as follows:

$$R(k) = \prod_{j=1}^{n} R_j(K_j) = \prod_{j=1}^{n}\left[1 - \left(1 - P_j\right)^{K_j}\right] \tag{11}$$

Then the value of $K_1, \ldots, K_n$ must meet the following equation set:

$$\begin{cases} \prod_{j=1}^{n} R_j(K_j) \geq R_0 & (12) \\ K_j = 1,2, \ldots, \; j = 1,2, \ldots n & (13) \\ \sum_{j=1}^{n} C_j K_j = \min(aire) & (14) \\ \sum_{j=1}^{n} C_j K_j \leq 612 & (15) \end{cases}$$

Since the reliability of the system must meet the requirement, $R_s = 0.95$, the total number of parts of the system is considered least.

According to series systems by n-parts, equality is seen in the following: $R(1,1,\ldots,1)=p_1 p_2 \ldots p_n$。 The same module is added to some sub-modules every time, until the reliability of the system is increased most quickly up to or exceeding R_s. Obviously, when the same module is added to the module in a parallel system in a situation where the reliability is $p_1, p_2, \ldots, p_n$ is smallest. According to the formula (12), (13), (14), and (15), the searching algorithm is as follows:

Algorithm 3.1 Using linear programming method to find the optimal solution. (MATLAB)

```
Input (Ri, Rs, Rp)
R=prod(Ri)
Te=Ri
while  R<Rs
 [T,j]=min(Te)
        Te(j)=1-(1-Ri(j)).^(Rp(j)+1)
        Rp(j)=Rp(j)+1
        R=prod(Te)
end while
Ri=Te
Output (R，Ri，Rp)
```

Ri--The reliability of each sub-module. **R_s----The target reliability of system.**

Rp--The initial number of each sub-module. **R-- System final reliability**

3 Experimental Results

Tables 4 show the backup programs obtained by the rating distribution method and the linear programming optimization.

Table 4: The optimizing backup program

Sub-module	Reliability (Initial)	Program 1		Program 2		Program 3	
		program	backup	program	backup	program	backup
control	0.9806	2	0.9996	2	0.9996	1	0.9806
sending	0.9678	2	0.9990	2	0.9990	2	0.9990
receiver	0.9491	2	0.9974	2	0.9974	2	0.9974
recovery	0.9806	2	0.9996	1	0.9806	2	0.9996
faulting	0.9967	1	0.9967	1	0.9967	1	0.9967
timing	0.9919	1	0.9919	1	0.9919	1	0.9919
credibility	0.9967	1	0.9967	1	0.9967	1	0.9967
baud rate selection	0.9967	1	0.9967	1	0.9967	1	0.9967
System	0.8674		0.9778		0.9592		0.9592

Note: The number of occupied CLBs is 163 in program 1; The number of occupied CLBs is 151 in program 2 and 3

Tables 4 show the results. The rating distribution method can be given an effective backup program of the SpaceWire node, which includes the backup control, sending, receiver, and recovery module. The two integrated programs given by the linear programming method also arrive at the same conclusion. The kinds of backup solution used can make the overall system reliability reach 0.9778. The number of occupied CLBs is 163. Obviously, when the reliability meets the requirements, the on-chip resources of FPGA are saved as compared to the backup overall SpaceWire node. Therefore, the goal of optimized redundant backup is realized by this method.

4 Conclusion

In this paper, we develop an effective program of SpaceWire node backup, which is calculated by the rating distribution method. This program is also achieved by the classical mathematical theory named the linear programming method. This analytic method represents the scientific rating distribution method on the complexity factor. In short, in order to combine the two methods, the reliability requirements of the backup design must first be optimized. Therefore, the design and optimization algorithm we provide plays an important role, which has practical significance in redundancy backup research.

The next step focuses on using classical mathematical theory to represent other rating factors of the rating distribution method analytically, as well as scientific and reasonable for factors such as the importance scale, working time, technical, etc. Thus, in theory, the rating distribution method is improved.

5 References

1. Xilinx, “Spartan-3E FPGA Family : Complete Data Sheet”, Xilinx, March 21, 2005

2. Liangqiao Li, Yaohua Xu, Shaofeng Dong, “Reliability technology and management”, Industry Press , 1991, p.150-155

3. Jinhua Cao, Pei Cheng, “Mathematical theory of reliability cited”, Higher education press China, 2006, p.37-76

4. Weibo Er, Xuchang Li, Weiqun Yang, "Based on Reliability Demand Model Analysis for Spare Parts of the Weapon System", Journal of Missiles and Guidance, vol27 No.1, 2007, p.332-336