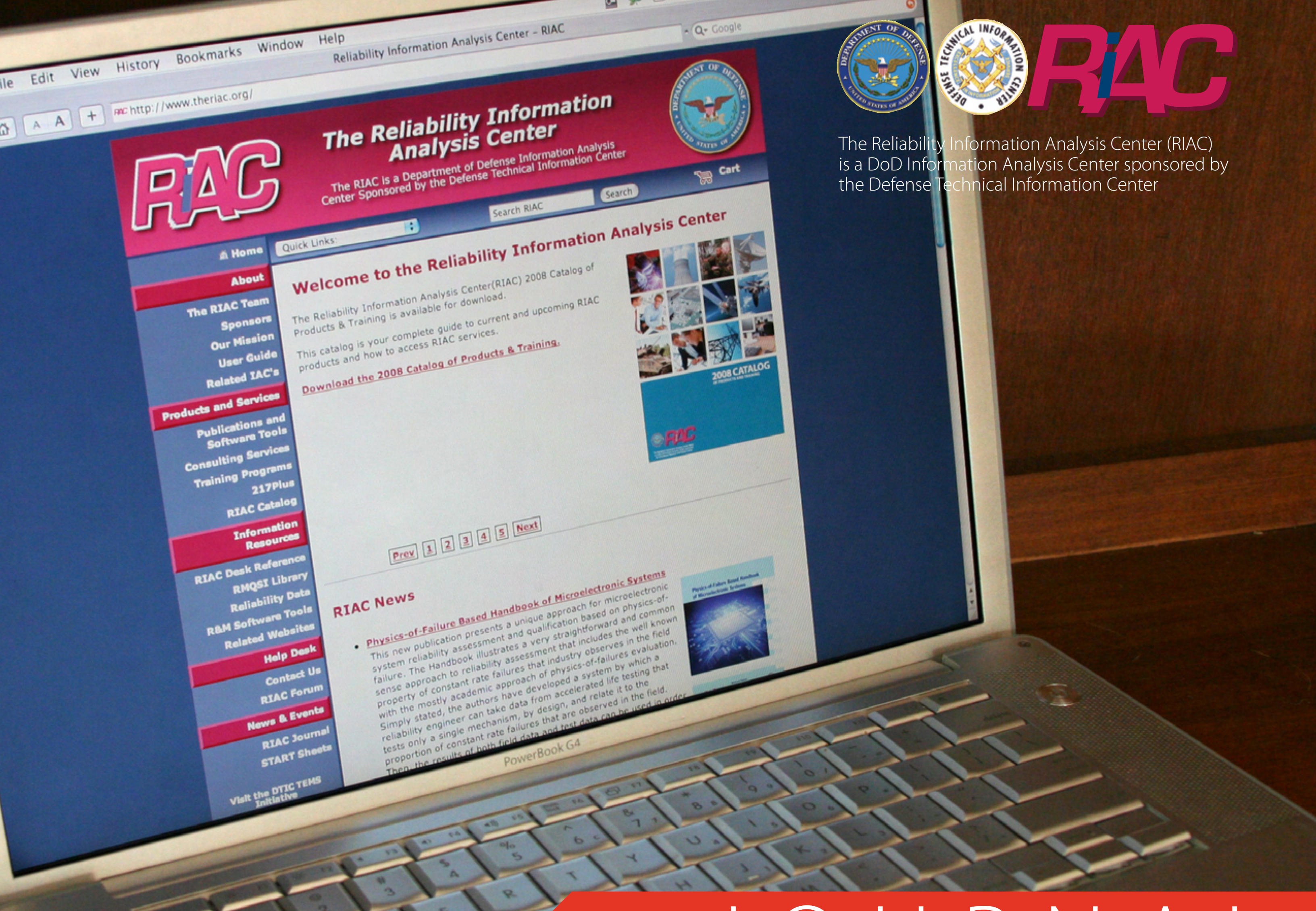

RIAC

The Reliability Information Analysis Center (RIAC) is a DoD Information Analysis Center sponsored by the Defense Technical Information Center

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HIGHLIGHTING THE NEW RIAC WEBSITE

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The Reliability Information Analysis Center (RIAC) is chartered by the DoD to support both government and commercial customers that have needs and interests in the areas of Reliability, Maintainability, Quality, Supportability and Interoperability (RMQSI). To meet its mission objectives, RIAC provides customers with RMQSI-related information, tools, training, and consulting expertise. With the release of RIAC's new and improved website (http://theRIAC.org), accessing technical content from the RIAC has never been easier. The redesign and expansion of our website allows the user to easily access the extensive body of RMQSI knowledge available from the RIAC.

Whether you are new to the reliability discipline, or are an expert reliability engineer, finding information on the RIAC website is a snap. With the new interactive home page (see Figure 1), which is updated frequently, you can view all the latest news concerning community events, as well as information pertaining to RIAC product releases and announcements for upcoming training courses. You can even access electronic copies of the RIAC Journal (released quarterly), including advance copies of the upcoming issue before it's been mailed to our customers.

We have also placed an extensive amount of high-value RMQSI-related documents directly on our site. This information can be used for training purposes or it can provide the knowledge and background needed for you to manage your programs or solve complex technical problems.

RIAC Desk Reference

The most exciting feature of the redesigned RIAC website is our new on-line technical resource known as the "Desk Reference". The intent of this feature is to freely distribute select, high-value documents and other information to all members of the RMQSI community. To populate this resource, the RIAC has worked diligently to convert many relevant documents into web-friendly formats that facilitate user access and convenience through the use of search engines. We have also developed and implemented exciting information technology solutions along the way that facilitate your ability to use our information so that you can become proficient in new tasks or find solutions to challenging RMQSI problems. Later in this section we will discuss some of these features, including a vastly improved interactive navigation bar which was specifically designed to help guide you through some of our more lengthy articles. Other highlights of the Desk Reference include a fast document searcher, a "Recommended Readings" sidebar, a "Read Later" list, and even customized reading suggestions based on articles that you previously viewed.

One of the key features of the "Desk Reference" enhancement is the powerful method we've employed to help you find the documents you need. Our previous website contained no dedicated search capability and relied mainly on Internet search engines to send people directly to the content they desired. While we still employ this strategy and have greatly improved the ability for search engines to index our site, we also created our own internal search engine which allows you to search through our extensive

Figure 1: New RIAC Homepage

database of articles and other technical content for specified keywords. In addition to searching through this database, the new search engine allows you to simultaneously search through the new RIAC Discussion Forum. Conducting a search in such a fashion enables a user to rapidly find complementary information. The search tool was constructed to allow the results of the document and forum queries to be displayed concurrently, thus facilitating the ability to analyze and employ all applicable information that resides on the website.

Figure 2 displays an image of an article viewed through the Desk Reference interface. In addition to the article itself, this interface employs a number of different components, including the navigation menu, a "Read Later" list, links to suggested articles, a "My Desk" feature, and the Discussion Forum. Each of these features is discussed in more detail below.

Navigation Menu

The navigation menu allows users to perform a multitude of tasks related to the article being displayed. One such task involves the capability to help the user navigate and read lengthy documents. The sidebar (Figure 3), which is displayed adjacent to the document being read, constantly updates itself so that you can look at the document's outline in the navigation menu and easily determine what section you are currently reading. As you scroll down the article and into a new section, the navigation menu updates and expands to show the detailed topics and content within that particular section. Another feature is that the menu allows you to change your view by parsing lengthy documents so that only the specific sections of the article or document being viewed are presented on your monitor. We also implemented a "Save My Spot" feature, which saves your location within the document. When returning to the page at a later time, you are instantly brought back to the location that you were last viewing. We have added a button that launches a Printer-Friendly version of the article to make printing more efficient. Finally, we've made our articles more accessible to the visually impaired by adding the ability to increase and decrease the font size of the article. Of course, if you don't need all of these features, we have included the ability to minimize the navigation window.

Figure 2: Desk Reference Interface

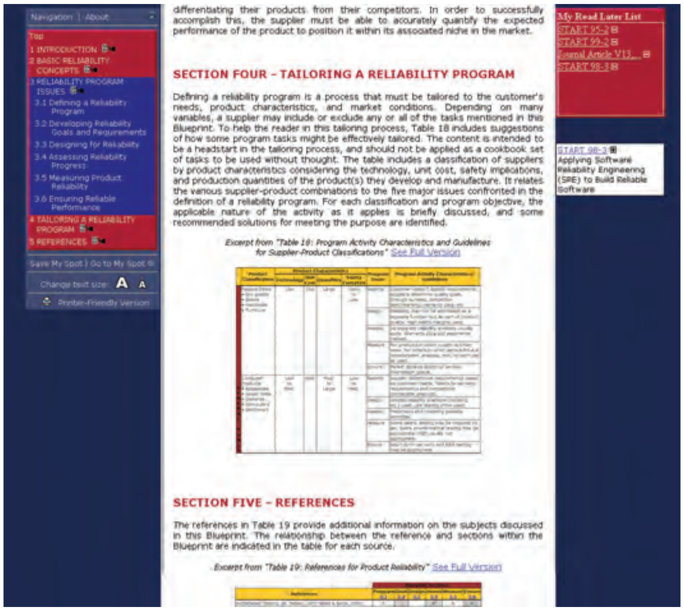

Figure 3: Desk Reference Sidebars

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Read Later List

On the right-hand side of the page is the "Read Later" list. While reading individual documents and articles within the Desk Reference, you will come across our recommendations for documents that provide additional in-depth perspectives on relevant topics. Next to our suggestions will be a plus sign, which, when clicked, will add a link to that article into your own "Read Later" list. The contents of the "Read Later" list remains accessible throughout the time spent using the Desk Reference. If you register for our free service, it can be saved for future access using the personalized "My Desk" feature, which is discussed below. Depending on the article being viewed, the RIAC's recommendations for further reading will appear in the top of the right hand pane, or placed in proximity to a relevant section within a larger document.

My Desk

The "My Desk" feature has been specifically designed to help you receive the most benefit from the Desk Reference. Since there is an extensive amount of information available through the Desk Reference, we felt it important to provide a capability that would help the user select articles that may be of interest and to help track which have been read. One capability that is resident within "My Desk" is the ability to store and access your individual "Read Later" list. This, in conjunction with the "Save My Spot" button, gives the user the ability to completely leave the Desk Reference and come back at a later date and pick up exactly where he or she left off. The most valuable feature of "My Desk" is the suggested reading section. The tool analyzes your reading history and provides you with a list of suggested articles and other products based on the specific keywords of interest that were used during your searches.

Discussion Forum

The RIAC has released a new on-line forum to allow for quick and easy inquiry submittals and community discussion. We have implemented an interface that is rich with features, but also easy to use. Posts from our past forum have been organized into specific topics within each of the RMQSI topical areas. The forum also includes its own search engine which allows you to search through the entire collection of discussions. In addition, the search engine allows you to search within a specific topic or for posts from a specific user.

RMQSI Library

The RIAC website now offers enhanced access to our extensive Library, which contains more than 150,000 RMQSI-related citations. To access this information, simply click on the "RMQSI Library" button, or choose the option from our quick links drop-down menu. This will enable you to search through the entire RIAC collection. We have also redesigned the library search algorithm so that results can be displayed much faster and with greater relevance to your query. RIAC understands that people need up-to-date information when making critical decisions. The library is continually updated by adding new citations and documents so that the latest knowledge can be located and applied to your needs.

RIAC Products

The procedures implemented through the new RIAC website have completely revamped the product ordering process. Products are now grouped into easy-to-follow categories that include Analysis Guides, Application Guides, Data Books, Best Practices, Quality Improvements, Reliable Application of Components, Software Products, Software Reliability, Web Downloadable, Quality, Reliability, and Supportability. In addition, an improved search capability that enables customers to rapidly identify products of interest has been developed (see Figure 5). The new tool employs a keyword searching

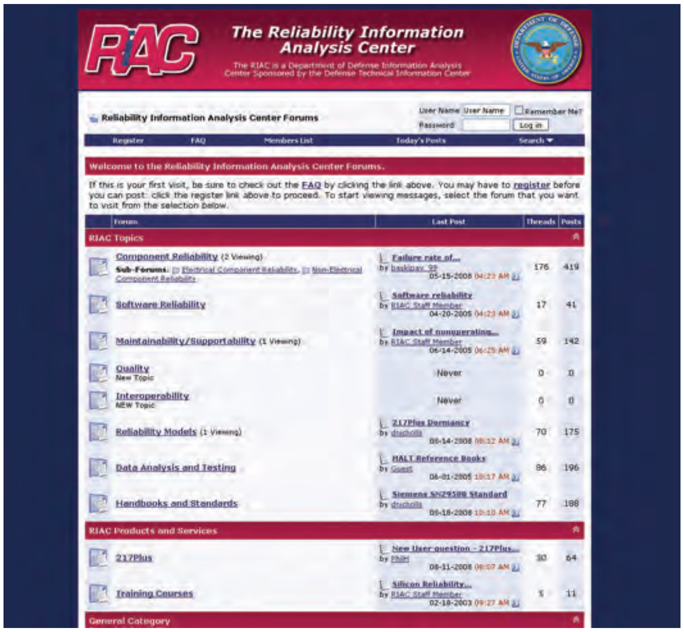

Figure 4: RIAC Forum

algorithm that will screen not only titles and product codes, but also individual product descriptions. This will allow you to rapidly find the products that you need.

We have implemented a completely new shopping cart interface and order forms so that placing your order is fast and easy. The user is allowed a great deal of flexibility with respect to receiving the products selected. Since most RIAC products are available in multiple formats, the website now groups products together and allows you to choose the format that best meets your needs. If your needs aren't immediate, many products allow you to have either a hardcopy or CD version of our product mailed to you. However, if a product is needed quickly, we also provide the option to download most products after purchase. All online product orders are processed immediately and an email is sent to the purchaser confirming the order. This email includes tracking information that allows you to monitor the status of your order.

For those who prefer to purchase their order off-line using a check, money order or purchase order, we can still accommodate your needs. In order to purchase products in this fashion, simply follow the same purchasing steps that you would normally employ to purchase on-line products and then click the "Buy off-line" button at the end of the last step. All the information you provide is captured and a printable order form is displayed, eliminating the need to fill in your billing, shipping, and order information by hand.

Registering online for our RIAC training courses has never been easier. We now provide the ability to group your training course registrations and other RIAC product requests into the same order. Instead of individual registrations, one person from your organization can now place an order to register as many training course attendees as desired, which eliminates repetitious registration actions (see Figure 6)

Conclusions

The RIAC continues to dedicate itself to providing our customers with up-to-date information pertaining to all aspects of RMQSI. We take great pride in being a leader in the RMQSI community and continually strive to raise the bar to enable improved customer satisfaction. Our redesigned website, along with our new "Desk Reference" information resource, has been specifically designed to make it easier for you to obtain and employ the information we possess in our database. We invite you to check out the revitalized RIAC website and its extended capabilities.

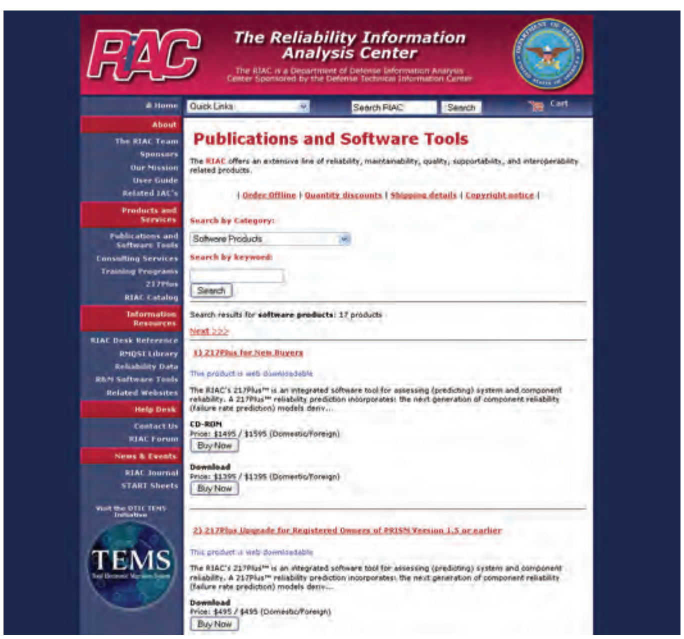

Figure 5: RIAC Product Search

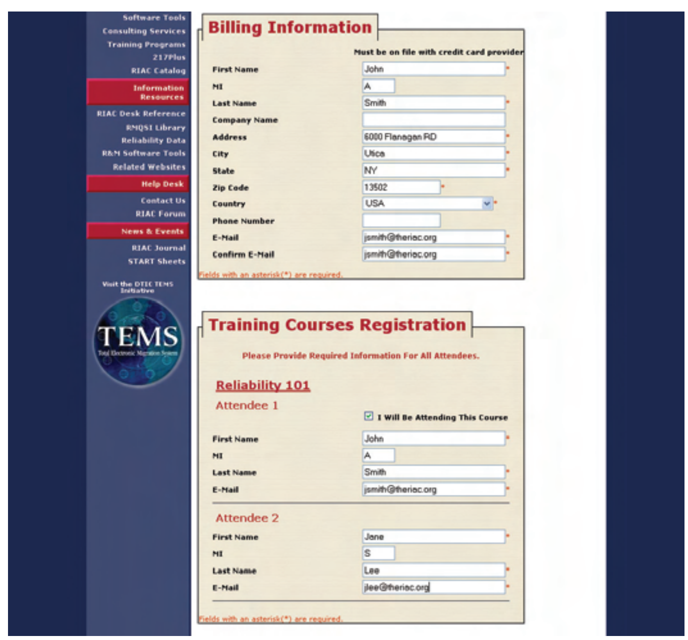

Figure 6: Training Registration Form

SPARES OPTIMIZATION ALGORITHM FOR CALCULATING RECOMMENDED SPARES

Vito Faraci, Jr.

Introduction

A typical problem that logistics engineers very often have to deal with is that of answering the question "How many spares will be required for successful completion of a mission or objective". The following is a typical example:

An aircraft carrier has 50 fighter airplanes on board. All planes utilize a certain black box that must be operational for mission success. There is no repair facility on board the carrier for this particular box, and the ship is usually out at sea for months at a time.

So naturally the question arises as to how many spare black boxes should be taken on board so that the carrier will have enough replacements for anticipated failures. The method most commonly used for calculating the recommended quantity of spares is the Cumulative Poisson Probability Algorithm, stated mathematically as

$$F(k,\ n\lambda t) = \sum_{j=0}^{k} \frac{(n\lambda t)^{j} \cdot \left(e^{-n\lambda t}\right)}{j\,!} \geq C$$

where,
λ = failure rate
t = operating time during service period of interest
n = quantity of items to be supported
C = confidence level that there will be a spare available when needed
k = recommended spares quantity where the cumulative Poisson probability $F(k;n\lambda t)$ exceeds the pre-selected confidence (adequacy) level C.

The objective of this article is to explain why and how the above equation (algorithm) works and to provide some insight into its origin.

Binomial Distribution

Because the Binomial Distribution provides the foundational combinatorial mathematics required to perform spares calculations, and is easier to comprehend mathematically, we will start by discussing the Binomial so as to understand the Poisson Distribution with more clarity and detail. The Binomial Probability Distribution (also known as the Binomial Expansion) is, in fact, more commonly known and, as mentioned before, easier to understand. However, what is not so commonly known is that the Binomial Probability Distribution can also be used as a spares calculating tool.

Recall from basic probability theory that the Binomial Probability Distribution is defined as follows:

$$\text{If } p + q = 1 \text{ then } (p+q)^{n} = \sum_{k=0}^{n} \frac{n!}{k!(n-k)!}\, p^{n-k} \cdot q^{k} = 1^{n} = 1$$

Example: Let p = 0.9, q = 0.1, and n = 3. Then,

$$(p+q)^{n} = 1 \cdot p^{3} + 3 \cdot p^{2}q + 3 \cdot pq^{2} + 1 \cdot q^{3}$$
$$= (.9 + .1)^{3} = 1 \cdot (.9)^{3} + 3 \cdot (.9)^{2}\,(.1) + 3 \cdot (.9)(.1)^{2} + 1 \cdot (.1)^{3}$$
$$= 0.729 + 0.243 + 0.027 + 0.001 = 1$$

The coefficients 1, 3, 3, and 1 are called the "Binomial Coefficients" = $\text{cmb}(n, k) = \dfrac{n!}{(n-k)!\ \cdot k!}$

where cmb(n, k) = number of ways k items can be selected from n items. Close examination of each term reveals that the exponent of p is equal to the number of components operational, the exponent of q is equal to the number of failed components, and the sum of the exponents of each term is always n.

In Microsoft Excel, cmb(n, k) can be calculated using the "COMBIN" function. Refer to Appendix 1 for an alternate method of calculating cmb(n, k) using the famous Pascal Triangle.

In the field of Reliability, the binomial expansion $(p+q)^{n}$ is used to calculate the probabilities of failure of n components with same failure rate operating in parallel (meaning all components operating at the same time), where p = probability of success, and q = probability of failure of any one component.

As an example, three black boxes are operating in parallel also referred to as operating "Active Redundant". What are the probabilities that no boxes fail, exactly one fails, exactly two fail, and exactly three fail, if the reliability (probability of success) of each box is 0.9? Therefore n = 3, p = 0.9, and q = 0.1, and

$$1 = (p+q)^3$$
$$1 = p^3 + 3p^2q + 3pq^2 + q^3$$
$$1 = (.9)^3 + 3(.9)^2(.1)+3(.9)(.1)^2 + (.1)^3$$

P(exactly 0 failures)
P(exactly 1 failure)
P(exactly 2 failures)
P(exactly 3 failures)

Answers:
0 fail = 0.729, 1 fail = 0.243, 2 fail = 0.027, 3 fail = 0.001

Note the above distribution of probabilities of failure can also be expressed as a distribution of probabilities of successes as follows:

$$1 = (p+q)^3$$
$$1 = p^3 + 3p^2q + 3pq^2 + q^3$$
$$1 = (.9)^3 + 3(.9)^2(.1)+3(.9)(.1)^2 + (.1)^3$$

P(exactly 3 successes)
P(exactly 2 successes)
P(exactly 1 success)
P(exactly 0 successes)

Note the two ways of saying the exact same thing.

With respect to components operating in parallel, in many applications mission success is defined as "all 3 operational", "2 or more operational", or "1 or more operational". A simple example of a "1 or more operational" mission success profile would be a 3 engine airplane designed to fly on one engine. By laws of nature, if an airplane can fly on one engine, it can also fly on two or more to achieve mission success. In this case, the "n or more operational" probabilities can be calculated using sums of selected terms of the binomial expansion as follows:

$$1 = (.9)^3 + 3(.9)^2(.1) + 3(.9)(.1)^2 + (.1)^3$$

P(all 3 operational) = 0.729 (sum of first 1 term)

$$1 = (.9)^3 + 3(.9)^2(.1) + 3(.9)(.1)^2 + (.1)^3$$

P(2 or more operational) = 0.972 (sum of first 2 terms)

$$1 = (.9)^3 + 3(.9)^2(.1) + 3(.9)(.1)^2 + (.1)^3$$

P(1 or more operational) = 0.999 (sum of first 3 terms)

This progressive list of sums of terms of the binomial expansion shown above is known as a Cumulative Binomial Distribution expressed mathematically and listed in the following table.

Table 1: Cumulative Binomial Distribution

Probability of Failure / Success Chart				
n = 3 items, k = # of failures, p = 0.9, q = 0.1				
		Binomial Terms	Binomial Cum	
# failures (k)	# successes (n-k)	Probability of exactly n-k successes	Probability of n-k or more successes	n-k or more successes
		$cmb(n,k) \cdot p^{n-k} \cdot q^k$	$\sum_{j=0}^{k} cmb(n,j) \cdot p^{n-j} \cdot q^j$	
0	3	0.729	0.729	3
1	2	0.243	0.972	2 or more
2	1	0.027	0.999	1 or more
3	0	0.001	1	0 or more

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Example of a Typical Spares Problem using Cumulative Binomial Distribution

The following example refers to the "typical problem" cited in the introduction using some hypothetical numbers:

> An aircraft carrier has 50 fighter airplanes on board. All planes utilize a certain black box that must be operational for mission success. There is no repair facility on board the carrier for this particular box, and the ship is usually out at sea for 26 week time intervals. All planes fly for an average of 3 hours a day, five days a week. The failure rate of one black box = λ = 131.521267 failures per million hours (FPMH). How many spare black boxes should be kept on board for a desired 95% confidence level that the carrier will have enough black box replacements for anticipated failures? How many for a 99% confidence level?

Solution:

From the mission profile, the total time requirement for mission operation is t = 3 x 5 x 26 = 390 hours. Using Probability of Success (Reliability) = p = $e^{-\lambda t}$, p and q are calculated as: p = $e^{-131.521267t/1000000}$ = 0.95, and q = 1 – p = 0.05 and the following Table 2 is constructed:

Note: λ = 131.521267 was chosen as the example such that p = $e^{-\lambda t}$ = 0.950000000244673, which is very close to 0.95.

Based on a mission profile, the confidence level is determined by a table look-up. Note from Table 2 (column 4), that there is a greater than 95% probability that 5 or less failures will occur. Therefore, if 5 spares were carried on board the carrier, it can be concluded that mission success would be achieved with greater than 95% probability (or 95% confidence level). Similarly, if 7 spares were carried on board, greater than 99% probability of mission success would be achieved.

Poisson Relationship (Correlation)

There is a theorem (see Appendix 2) that proves that if n is large and λt is small, the Poisson Distribution is a good approximation for the Binomial Distribution. Stated mathematically,

$$P(n\lambda t, \mathrm{k}) = \frac{(\mathrm{n}\lambda \mathrm{t})^{\mathrm{k}} \cdot \mathrm{e}^{-\mathrm{n}\lambda \mathrm{t}}}{\mathrm{k}!} = \text{probability of exactly k}$$

failures, is approximately equal to cmb(n,k) · p^{n-k} · q^k term for term. Table 3 illustrates the correlation.

Note the correlation between the Binomial and Poisson expressions for exactly n-k successes (columns 3 and 4), and the cumulative expressions (columns 5 and 6).

Note that a closer observation reveals that even with a small n, a large p will yield very close approximations, as can be seen in Table 5. See how the "Cum Deltas" decrease as p increases.

Table 2: Determining Confidence Level

Binomial Probability of Failure / Success Chart				
n = 50 items, k = # of failures, p = 0.95, q = 0.05				
		Individual Terms	Cumulative Terms	
# failures (k)	# successes (n-k)	Probability of exactly k failures	Probability of k or more failures	Confidence Level C
		cmb(n,k) · p^{n-k} · q^k	$\sum_{j=0}^{k}$ cmb(n,j) · p^{n-j} · q^j	
0	50	0.076944976	0.076944976	
1	49	0.202486779	0.279431755	
2	48	0.261101371	0.540533126	
3	47	0.219874838	0.760407964	
4	46	0.135975228	0.896383191	
5	45	0.065840636	0.962223828	← greater than 95%
6	44	0.025989725	0.988213552	
7	43	0.008598104	0.996811657	← greater than 99%
8	42	0.002432358	0.999244015	
9	41	0.000597421	0.999841437	

Table 3: Binomial - Poisson Correlation

n = 50 items, k = # of failures, p = 0.95, q = 0.05, nλt = 50 x 131.521267 x 390 /1000000					
		Probability of exactly k failures		Probability of k or less failures	
k	n-k	Binomial	Poisson	Binomial Cum	Poisson Cum
		$cmb(n,k) \cdot p^{n-k} \cdot q^k$	$\frac{(n\lambda t)^k \cdot e^{-n\lambda t}}{k!}$	$\sum_{j=0}^{k} cmb(n,j) \cdot p^{n-j} \cdot q^j$	$\sum_{j=0}^{k} \frac{(n\lambda t)^j \cdot e^{-n\lambda t}}{j!}$
0	50	0.076944976	0.076944976	0.076944976	0.076944976
1	49	0.202486779	0.197338065	0.279431755	0.274283041
2	48	0.261101371	0.253052985	0.540533126	0.527336026
3	47	0.219874838	0.21633202	0.760407964	0.743668047
4	46	0.135975228	0.138704774	0.896383191	0.882372821
5	45	0.065840636	0.071146248	0.962223828	0.953519068
6	44	0.025989725	0.030411045	0.988213552	0.983930114
7	43	0.008598104	0.011142019	0.996811657	0.995072133
8	42	0.002432358	0.003571943	0.999244015	0.998644076
9	41	0.000597421	0.001017871	0.999841437	0.999661946

Table 4: Determining Confidence Level (Using Poisson)

n = 50 items, k = # of failures, p = 0.95, q = 0.05, nλt = 50 x 131.521267 x 390 /1000000				
		Probability of k or less failures		
k	n-k	Poisson	Poisson Cum	Confidence Level C
		$\frac{(n\lambda t)^k \cdot e^{-n\lambda t}}{k!}$	$\sum_{j=0}^{k} \frac{(n\lambda t)^j \cdot e^{-n\lambda t}}{j!}$	
0	50	0.076944976	0.076944976	
1	49	0.197338065	0.274283041	
2	48	0.253052985	0.527336026	
3	47	0.21633202	0.743668047	
4	46	0.138704774	0.882372821	
5	45	0.071146248	0.953519068	← greater than 95%
6	44	0.030411045	0.983930114	
7	43	0.011142019	0.995072133	← greater than 99%
8	42	0.003571943	0.998644076	
9	41	0.001017871	0.999661946	

Conclusion

As previously mentioned, the method most commonly used for calculating the recommended quantity of spares is the Cumulative Poisson Probability Algorithm. This algorithm is basically a table construction and look-up as illustrated in Tables 2 and 4.

The Binomial Distribution provides the framework for the proper combinatorial mathematics required to perform a Spares calculation. Theoretically, it will yield solutions with greater accuracy since the Poisson is an approximation. However, with large n, the cmb(n, k) terms of the Binomial can get very large, and by themselves may induce "round off" error in the calculations. Although with modern day computers, it remains to be proven which algorithm will yield the least amount of error. Also, in light of the fact that many times there is a margin of error in the failure rate calculations, any additional error yielded by either distribution will be insignificant in the final analysis.

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Table 5: Correlation with Small n

n = 3 items, k = # of failures, $p = e^{-\lambda t}$ $q = 1 - e^{-\lambda t}$				
		Probability of k or less failures (n-k or more successes)		
k	n-k	Binomial Cum	Poisson Cum	Cum Delta
		$\sum_{j=0}^{k} cmb(n,j) \cdot p^{n-j} \cdot q^{j}$	$\sum_{j=0}^{k} \frac{(n\lambda t)^{j} \cdot e^{-n\lambda t}}{j!}$	
$p = 0.95$, $q = 0.05$, $t = 390$ hrs, $\lambda = 131.521267$				
0	3	0.857375	0.857375	0
1	2	0.99275	0.989307765	0.003442235
2	1	0.999875	0.999458664	0.000416336
3	0	1	0.999979337	2.06629E-05
$p = 0.9$, $q = 0.1$, $t = 390$ hrs, $\lambda = 270.155168$				
0	3	0.729	0.729	0
1	2	0.972	0.959423448	0.012576552
2	1	0.999	0.995839748	0.003160252
3	0	1	0.999676588	0.000323412
$p = 0.8$, $q = 0.2$, $t = 390$ hrs, $\lambda = 572.162952$				
0	3	0.512	0.512	0
1	2	0.896	0.854748495	0.041251505
2	1	0.992	0.969471669	0.022528331
3	0	1	0.995071406	0.004928594
$p = 0.7$, $q = 0.3$, $t = 390$ hrs, $\lambda = 914.551138$				
0	3	0.343	0.343	0
1	2	0.784	0.710018517	0.073981483
2	1	0.973	0.906377981	0.066622019
3	0	1	0.976414482	0.023585518
$p = 0.6$, $q = 0.4$, $t = 390$ hrs, $\lambda = 1309.809291$				
0	3	0.216	0.216	0
1	2	0.648	0.547015004	0.100984996
2	1	0.936	0.800651423	0.135348577
3	0	1	0.930215405	0.069784595

Appendix 1

Calculating cmb(n, k) using Pascal's Triangle

Recall also from basic probability theory a simple way of calculating Binomial Coefficients using the famous Pascal's Triangle.

Pascal's Triangle

n	n! / (n-k)!k!
1	1 1
2	1 2 1
3	1 3 3 1
4	1 4 6 4 1
5	1 5 10 10 5 1
6	1 6 15 20 15 6 1
7	1 7 21 35 35 21 7 1
	k = 0 1 2 3 4 5 6 7

With respect to the triangle, n = row number and k = position number starting with k = 0.
Example cmb(7, 2) = 7! / (5!·2!) = 21.
See 7th row, position 2.

Notes:

- Table entries also known as combinatorial numbers
- cmb(n, 0) = 1 and cmb(n, n) = 1
- cmb short for combinations

Note that each entry in the Triangle is the sum of the closest two entries in the row immediately above.

Appendix 2

Theorem: (Poisson Approximation to the Binomial)

If n is large and λt is small, and $p = e^{-\lambda t}$, then $P(k) = \dfrac{n!}{k!(n-k)!} p^{n-k} q^k \approx \dfrac{(n\lambda t)^k}{k!} \cdot e^{-n\lambda t}$

Proof :

$$P(k) = \frac{n!}{k!(n-k)!} p^{n-k} q^k = \frac{\overbrace{n(n-1)(n-2)\cdots(n-k+1)}^{k \text{ terms}}}{k!} \cdot p^{n-k} q^k \approx \frac{n^k}{k!} \cdot p^{n-k} q^k \quad \text{since n is large}$$

$$= \frac{n^k}{k!} \cdot (e^{-\lambda t})^{n-k} \cdot (1-e^{-\lambda t})^k = \frac{n^k}{k!} \cdot \frac{e^{-n\lambda t}}{e^{-k\lambda t}} \cdot (1-e^{-\lambda t})^k = \frac{n^k}{k!} \cdot e^{-n\lambda t} \cdot \frac{(1-e^{-\lambda t})^k}{(e^{-\lambda t})^k}$$

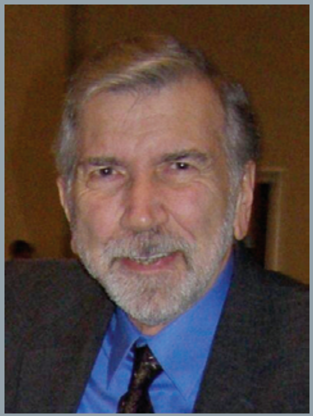
$$= \frac{n^k}{k!} \cdot e^{-n\lambda t} \cdot (e^{\lambda t} - 1)^k$$

$$\text{Now } e^{\lambda t} = 1 + \lambda t + \frac{(\lambda t)^2}{2!} + \frac{(\lambda t)^3}{3!} + \frac{(\lambda t)^4}{4!} + \cdots \Rightarrow e^{\lambda t} - 1 = \lambda t + \frac{(\lambda t)^2}{2!} + \frac{(\lambda t)^3}{3!} + \frac{(\lambda t)^4}{4!} + \cdots \Rightarrow$$

$$e^{\lambda t} - 1 = \lambda t \left(1 + \frac{\lambda t}{2!} + \frac{(\lambda t)^2}{3!} + \frac{(\lambda t)^2}{4!} + \cdots\right) \Rightarrow (e^{\lambda t} - 1)^k = (\lambda t)^k \left(1 + \frac{\lambda t}{2!} + \frac{(\lambda t)^2}{3!} + \frac{(\lambda t)^2}{4!} + \cdots\right)^k$$

$$\text{since } \lambda t \text{ is small } (e^{\lambda t} - 1)^k \approx (\lambda t)^k \cdot 1 \Rightarrow P(k) \approx \frac{n^k}{k!} \cdot e^{-n\lambda t} \cdot (\lambda t)^k = \frac{(n\lambda t)^k}{k!} \cdot e^{-n\lambda t} \quad //$$

About the Author



Vito Faraci is a mathematician by education, and an electrical engineer by trade. He has 20 years experience with qualitative and quantitative analyses of Reliability, Built-In-Test, and safety-related events. He has also served as a Reliability and Markov Analysis consultant for the Federal Aviation Administration and commercial airlines. He has given lectures and seminars in the United States and Canada on the subject of calculating probability of failure of electrical and mechanical components and systems. Mr. Faraci has also served as an adjunct math professor at New York Institute of Technology.

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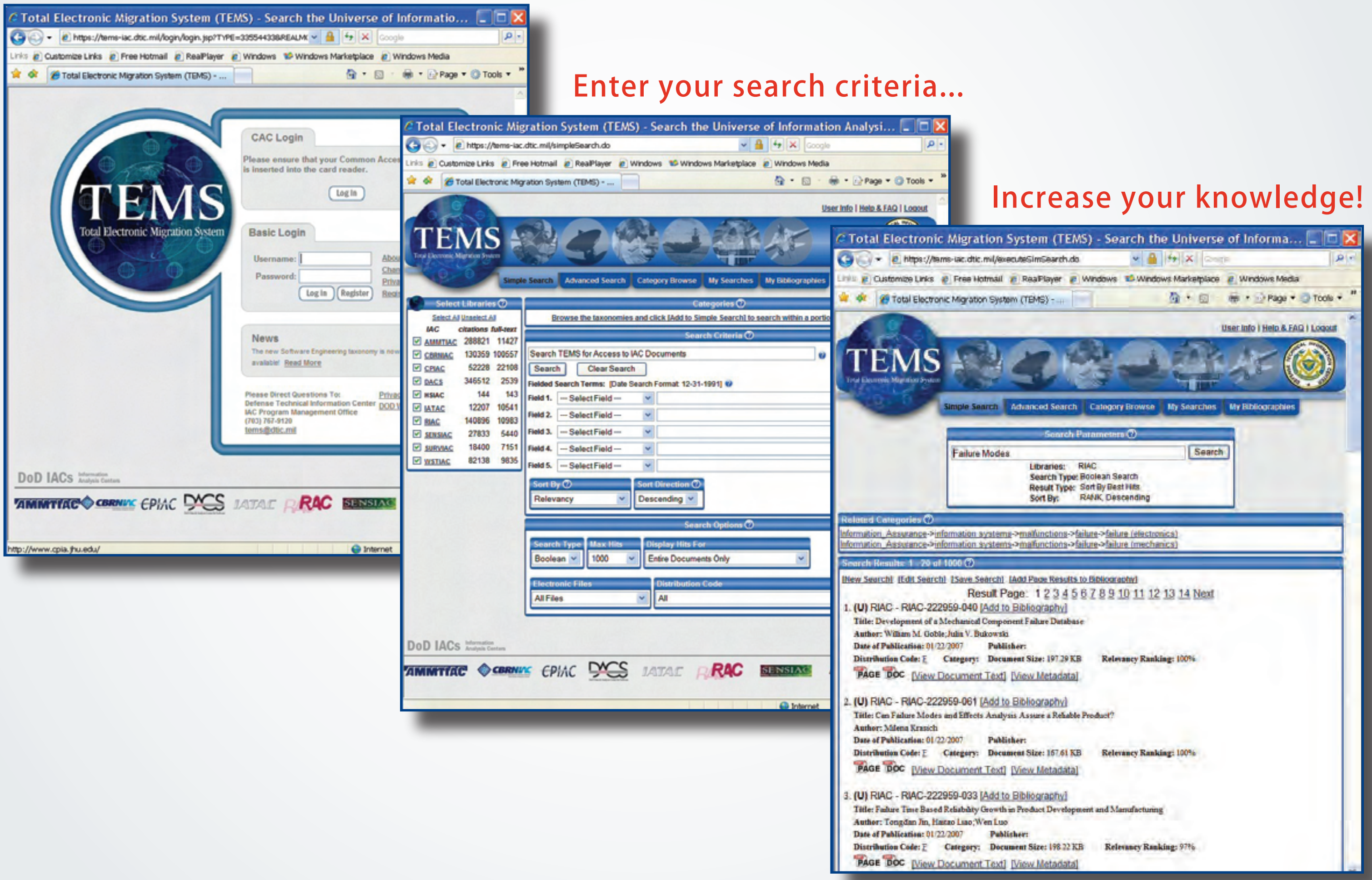

THE JOURNAL OF THE RELIABILITY INFORMATION ANALYSIS CENTER // THIRD QUARTER - 2008

The Journal of the Reliability Information Analysis Center is published quarterly by the Reliability Information Analysis Center (RIAC). The RIAC is a DoD Information Analysis Center (IAC) sponsored by the Defense Technical Information Center (DTIC) and operated by a team led by Wyle Laboratories, and including Quanterion Solutions Incorporated, the Center for Risk and Reliability at the University of Maryland, the Penn State University Applied Research Lab (ARL) and the State University of New York Institute of Technology (SUNYIT).

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Fishing For Data

DoD has authorized a revision of MIL-HDBK-217, the leading method for electronic reliability predictions. A working group consisting of government and private industry has been organized to lead this effort. The working group is soliciting part data to capture current part performance that can be used in the failure rate models to predict reliability. **NSWC Crane is the Preparing Activity for MIL-HDBK-217** and is leading the revision effort.

Recognizing the business sensitivity of part data, all submissions to support the MIL-HDBK-217 update effort will be screened, qualified and processed through the DoD-funded, DTIC-sponsored Reliability Information Analysis Center (RIAC; formerly known as the Reliability Analysis Center - RAC). As part of its charter as an unbiased, third-party agency of the DoD, the RIAC routinely executes Nondisclosure Agreements (NDAs) to protect proprietary data. The RIAC will ensure that all submitted data is properly sanitized, such that no proprietary information will be provided to the at-large MIL-HDBK-217 Working Group.

NSWC Crane would like your help in collecting two types of part data: test and field data. The following is the information we would like to have for all part types covered by MIL-HDBK-217 but we will accept any dependable data that is available. The more that is known about the data we receive, the better the failure rate predictions can be. **For more information on this process, please contact Jeffrey Harms at NSWC Crane (Jeffrey.harms@navy.mil)**.

Part Field Data

- **Part Information**
  - Type/Family
  - Technology
  - Package Style (DIP, Flat Pack, SM, Ball Grid Array, etc)
  - Part Quality Level
    - Commercial
    - Industrial
    - Automotive
    - Military
    - Space
  - Product Maturity (How long in service?)

- **Application**
  - Mission Profile (How was the part used)
    - Operating & Non-Operating
      - Time (Cycle time)
      - Environment (List various environments and temperatures the part has been exposed to)
  - Failures
    - Number of parts that have failed during the operation?
    - Root Cause (What was the part failure mode and the predominant failure mechanism?)
    - Time to Failure (Operating hours to the failure?)
    - Sample size? (Total quantity in the field)

Part Test Data

This type of part data could be from end-user, third-party or component manufacturer testing that has been performed on the part or part family

- **Test**
  - Test Environment/Conditions
    - What was the test temperature for the part?
    - Number of test hours or cycles?
    - Bias (Was voltage, current, dynamic patterns applied during the test?)
  - Failures
    - Number of parts that failed the test?
    - Root Cause (What was the part failure mode and the predominant failure mechanism?)
    - Time/Cycles to Failure (When did the device fail?)
    - Sample size? (Total quantity under test)

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PREDICTING RELIABILITY OF MMICS USING MONTE CARLO ANALYTICAL TECHNIQUES (PART 3 OF 3)

Aris Christou
RIAC (University of Maryland)

Part 1 of this article, published in the 1st Quarter 2008 issue of the RIAC Journal, addressed the methodology used to estimate monolithic microwave integrated circuit (MMIC) high temperature performance. Part 2 in the series, published in the 2nd Quarter 2008 issue of the Journal, covered MMIC model development. This last installment will discuss validation of the MMIC reliability model.

Validation of MMIC Reliability Model

The two circuit examples previously presented in Part 2 of this article have been simulated. For **Case 1**, the correlations between FETs of both the transimpedence amplifier (TIA) and the low noise amplifier (LNA) have been estimated by SPICE circuit analysis, and the Monte Carlo reliability simulations for both MMICs have also been performed. For **Case 2**, the LNA and power amplifier have been analyzed for validation.

LNA and TIA High Temperature Analysis

The assumptions for the reliability analysis are:

1) The relationship between channel temperature (T_j) and median life (t_m) is given by the Arrhenius equation as:

$$t_m = t_{mo} \exp\left[\frac{Ea}{k\,(T_j + 273)}\right]$$

where, t_{mo} = 8.332×10^{-15} for power type or 1.405×10^{-12} for the LNA, and
k = 8.6×10^{-5} eV/°K

2) The median life t_m at temperature T_m can be estimated by the given activation energy (Ea), test temperature (T_o) and median life (t_o):

$$t_m = t_{mo} \exp\left[\frac{Ea}{k\left(\frac{1}{T_o} + \frac{1}{T_m}\right)}\right]$$

The overall activation energy was calculated to be 1.6eV for each of the individual FETs.

3) Time to failure data of the MMIC components tested previously by the manufacturer most closely fits a lognormal distribution. Therefore, lognormal distributions are used for all FETs. The lognormal probability distribution function $f(t)$ is given as:

$$f(t) = \frac{1}{t\sigma\sqrt{2\pi}} \exp\left[\frac{1}{2}\left(\frac{\ln t - \ln t_m}{\sigma}\right)^2\right]$$

where σ (standard deviation) and t_m (median life) are two parameters that are given to determine operational lifetime t.

4) The interactions between FETs can be estimated by applying a weighting factor, $W_{ij} = 1/(1 - r_{ij})$ to modify the time to failure of the surviving components as previously discussed in Part 2 of this article.

5) The life performance of passive components can be neglected. The computational schematic for Monte Carlo technique applied to the TIA and the LNA MMIC reliability analysis is shown in Figure 1, and its algorithm is the following:

```
INPUT N (the desired sampling size)
While number of sampling n <= N
{For each sampling
        {Input number NC of components of the system and
        Group them into dependence or independence
        groups individually
        While i <= NC
                {Input sigma s and median life tm
                Select a random number x
                Transform random number x to random
                time to failure TTF based on its life distri-
                bution}
                Determine the component which is failed
                first and let its time to failure be T1.
                While j <= NC - 1
                {Modify the time to failure of all surviving
                components with a weighing factor w(ni,
                nj) based on their correlated relations.}
```

Determine system time to failure Ti
Compute reliability, MTTF and error

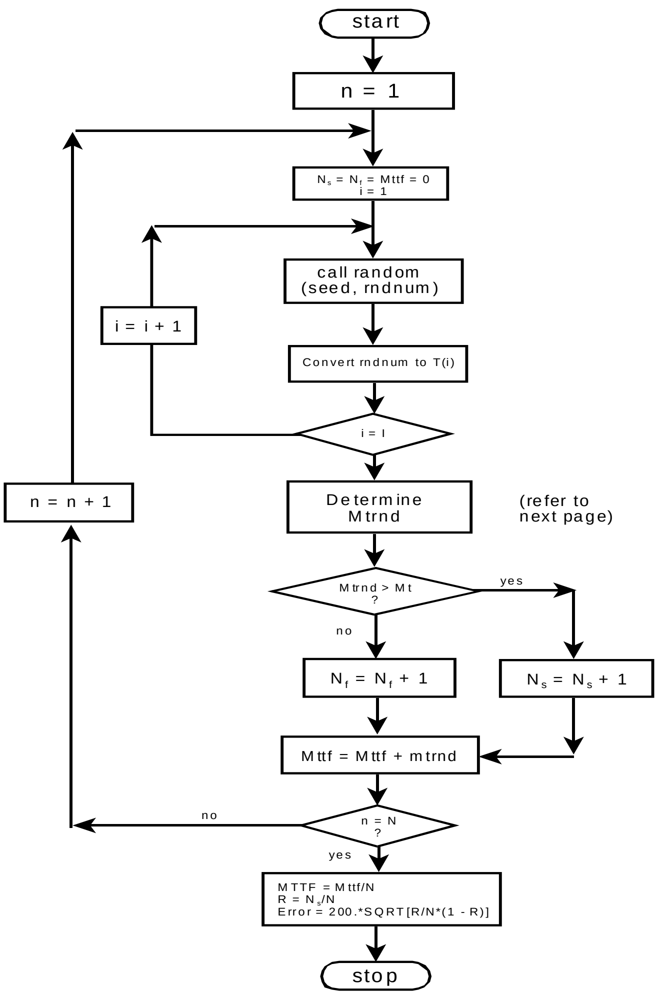

Figure 1: *Flow Chart for Calculation of MMIC MTTF*

LNA and Power Amplifier Reliability Analysis

The reliability analysis of both the amplifiers is similar as in the previous case, except that the s-dependent groups must be identified and weighting factors must be estimated by the equation under assumption 2. With some minor modifications, the algorithm and computer program for both TIA and LNA are still applicable for both the LNA and the power amplifier, (see Figure 2).

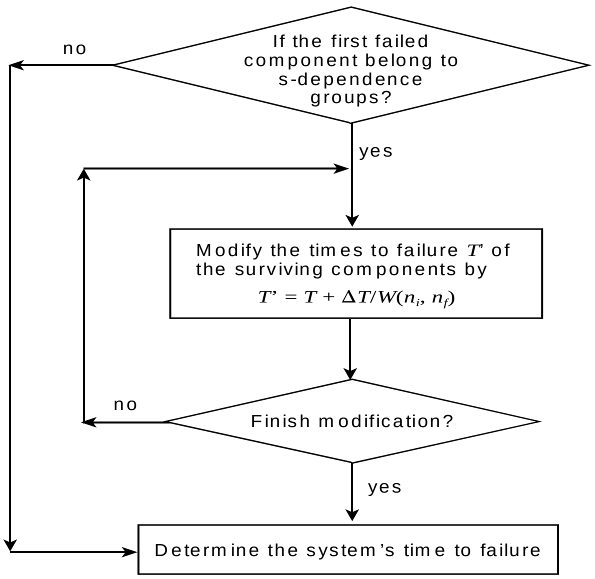

Figure 2: *The subroutine to estimate the modified MMIC time to failure*

Simulation Results

The results of the reliability simulation for TIA, and the LNA and power amplifier based on discrete component data are shown in Figures 3 to 51. The simulations by Monte Carlo techniques for both the dependent (modified by a weighting factor) and independent (based on the MIL-HDBK method) cases have been performed. The results show that the estimation of MMIC life, including interactions between FETs, is closer to experimental data than the estimation without taking into account the interactions. The results also indicate that interdependencies between devices is an important consideration and cannot be ignored.

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Figures 3 to 5 show that the simulations give a conservative estimation of the MTTF. The excellent agreement even holds for the temperature range of 225°C through 325°C, thus indicating that the simulation technique is applicable for high temperature simulations, where large non-linearities exist in the circuit's material properties. This investigation has therefore presented the simulation methodology for analog circuits operating in microwave systems such as MMICs. The approach outlined in this paper may be used for analog type circuits where the correlation coefficients have been identified.

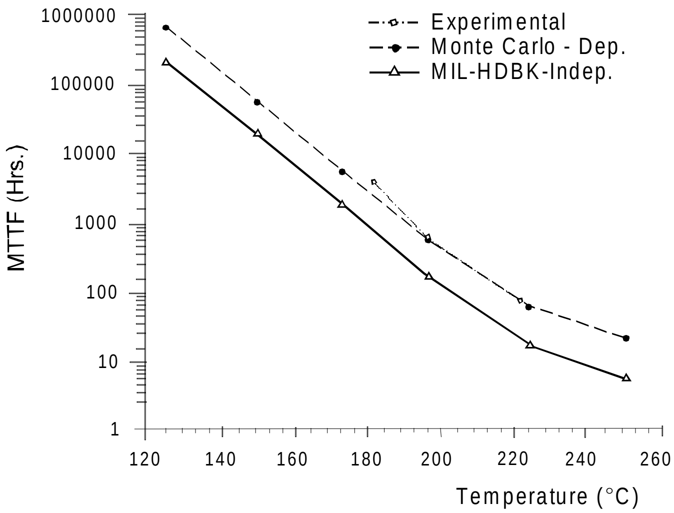

Figure 3: *MTTF versus Temperature for TIA*

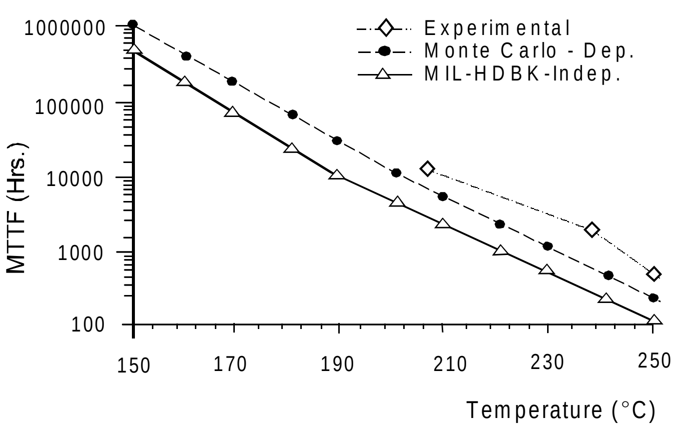

Figure 4: *MTTF versus Temperature for the LNA*

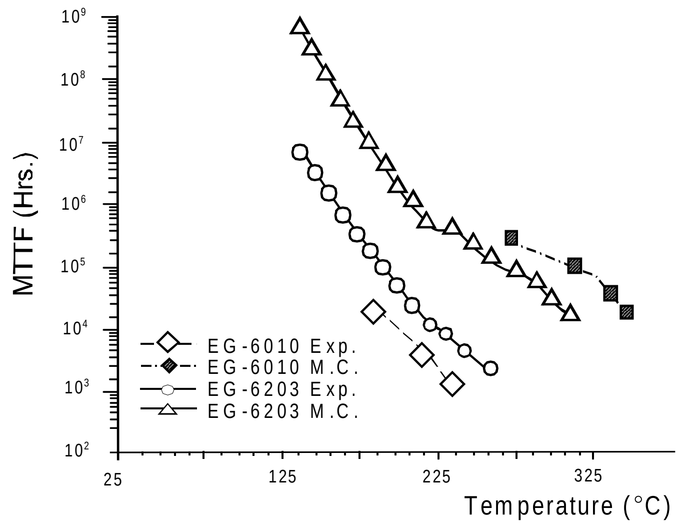

Figure 5: *MTTF versus Temperature for the LNA and Power Amplifier*

Conclusions

In the case of a complex MMIC circuit, it is not plausible to attain the analytical reliability by the Markov approach for constant failure rate, which perhaps is the best and most straightforward analytical approach to computations in systems with dependence. The equations become numerous and out of control for a large MMIC system, and the Markov method may break down when failure rates become non-constant. We have shown that the Monte Carlo technique is the appropriate methodology for predicting reliability of such complex circuits. We have successfully established a new reliability simulation model for MMICs and have shown that it has a wide applicability to analog circuits in general. The reliability model will be applicable over a wide temperature range and hence may be used for microwave systems.

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THE RIAC 217PLUS™ TRANSISTOR AND THYRISTOR FAILURE RATE MODELS

David Nicholls, RIAC (Quanterion Solutions Incorporated)

In a previous edition of the RIAC Journal [Reference 1], we provided a high-level introduction to the 217Plus™ component failure rate prediction models, and in the last five editions we presented the 217Plus™ capacitor and diode failure rate models [Reference 2], the integrated circuit and inductor failure rate models [Reference 3], the transformer and optoelectronic device models [Reference 4], the switch and relay models [Reference 5] and the connector and resistor models [Reference 6].

In this edition of the Journal, we present the Transistor and Thyristor component models in their entirety. A brief example will be provided at the end of the article.

217Plus™ Transistor Failure Rate Model

The failure rate equation for transistors [Reference 7] is:

$$\lambda_P = \pi_G\left(\lambda_{OB}\pi_{DCO}\pi_{TO} + \lambda_{EB}\pi_{DCN}\pi_{TE} + \lambda_{TCB}\pi_{CR}\pi_{DT}\right) + \lambda_{SJB}\pi_{SJDT} + \lambda_{IND}$$

where,

λ_P = Predicted failure rate, failures per million calendar hours

π_G = Reliability growth failure rate multiplier:

$$\pi_G = e^{(-\beta(Y-1993))}$$

β = *Growth constant. Function of transistor type (see Table 1)*

λ_{OB} = Base failure rate, operating. Function of transistor type (see Table 1)

π_{DCO} = Failure rate multiplier for duty cycle, operating:

$$\pi_{DCO} = \frac{DC}{DC_{1op}}$$

DC_{1op} = *Constant. Function of transistor type (see Table 1)*

π_{TO} = Failure rate multiplier for temperature, operating:

$$\pi_{TO} = e^{\left(\frac{-Ea_{op}}{0.00008617}\left(\frac{1}{T_{AO}+T_R+273} - \frac{1}{298}\right)\right)}$$

Ea_{op} = *Activation energy, operating. Function of transistor type (see Table 1).*

T_R = *The junction temperature rise above the ambient operating temperature (T_{AO}). The junction temperature is therefore $T_{AO} + T_R$. T_R can be determined in several ways:*

$T_{Rdefault}$ = Default temperature rise (see Table 1)

T_R = Actual (measured) temperature rise, if known

$T_R = \Theta_{JA} * P$
where Θ_{JA} is the junction-to-ambient thermal impedance and P is the power dissipated by the transistor

$T_R = \Theta_{JC} * P$
where Θ_{JC} is the junction-to-case thermal impedance and P is the power dissipated by the transistor

If this option is used, then T_{AO} should be replaced by T_C, the component case temperature, in the equation for π_{TO}

$T_R = \Delta T * S$
where ΔT is the difference in junction temperature between no power dissipated and full rated power dissipated, and S is the stress ratio and is equal to the actual forward current divided by the rated forward current

π_S = Failure rate multiplier stress

For Bipolar transistors:

$$\pi_S = 0.21e^{(0.31V_S)}$$

$$V_S = \frac{V_{CEapplied}}{V_{CErated}}$$

For all other transistor types, $\pi_S = 1$

Default V_S = *Constant. Function of transistor type (see Table 1)*

λ_{EB} = Base failure rate, environmental (see Table 1)

π_{DCN} = Failure rate multiplier, duty cycle – nonoperating:

$$\pi_{DCN} = \frac{1 - DC}{DC_{1nonop}}$$

DC_{1nonop} = *Constant. Function of transistor type (see Table 1)*

π_{TE} = Failure rate multiplier, temperature – humidity:

$$\pi_{TE} = e^{\left(\frac{-Ea_{nonop}}{0.00008617}\left(\frac{1}{T_{AE}+273} - \frac{1}{298}\right)\right)}$$

Ea_{nonop} = *Activation energy, nonoperating. Function of transistor type (see Table 1)*

λ_{TCB} = Base failure rate, temperature cycling (see Table 1)

π_{CR} = Failure rate multiplier, cycling rate:

$$\pi_{CR} = \frac{CR}{CR_1}$$

CR_1 = *Constant. Function of transistor type (see Table 1)*

π_{DT} = Failure rate multiplier, delta temperature:

$$\pi_{DT} = \left(\frac{T_{AO} + T_R - T_{AE}}{DT_1}\right)^2$$

DT_1 = *Constant. Function of transistor type (see Table 1)*

λ_{SJB} = Base failure rate, solder joint (see Table 1)

π_{SJDT} = Failure rate multiplier, solder joint delta temperature:

$$\pi_{SJDT} = \left(\frac{T_{AO} + T_R - T_{AE}}{44}\right)^{2.26}$$

λ_{IND} = Failure rate, electrical overstress (see Table 1)

Table 1: Transistor Parameters

Part Type	λ_{OB}	λ_{EB}	λ_{TCB}	λ_{IND}	λ_{SJB}	β	DC_{1op}	Ea_{op}	$T_{Rdefault}$	$V_{Sdefault}$	DC_{1nonop}	Ea_{nonop}	CR_1	DT_1
Bipolar, Germanium	0.001586	0.0007359	0.000965	0.02954	.0015	0.281	0.23	0.2	60	.5	0.77	0.3	754.38	80
Bipolar, High Frequency, Microwave	0.000106	0.0005206	0.0000536	0.003106	.0015	0.269	0.23	0.2	60	.5	0.77	0.3	754.38	80
Bipolar, Low Frequency	0.000235	0.0001657	0.00016	0.008899	.0015	0.281	0.23	0.2	60	.5	0.77	0.3	754.38	80
Bipolar, Multiple	0.000621	0.0004759	0.000648	0.00754	.0015	0.281	0.23	0.2	60	.5	0.77	0.3	754.38	80
Field Effect, High Frequency, Microwave	0.001049	0.0004674	0.000225	0.04541	.0015	0.397	0.23	0.2	60	N/A	0.77	0.3	754.38	80
Field Effect, Low Frequency, Silicon	0.000195	0.000333	0.000255	0.01099	.0015	0.397	0.23	0.2	60	N/A	0.77	0.3	754.38	80
Field Effect, Multiple	0.00022	0.0004209	0.00076	0.01618	.0015	0.269	0.23	0.2	60	N/A	0.77	0.3	754.38	80
Field Effect, Unijunction	0.000143	0.0002657	0.0000278	0.002462	.0015	0.397	0.23	0.2	60	N/A	0.77	0.3	754.38	80
General	0.0000776	0.00002607	0.0000193	0.03433	.0015	0.397	0.23	0.2	60	.5	0.77	0.3	754.38	80

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NOTE: Environment-type and equipment-dependent default values for DC, TAO, TAE and CR were previously presented in Reference 1, where,

DC = Duty cycle (the percent of calendar time that the system in which the component is operating is in an operational state)
T_{AO} = Ambient temperature, operating (in degrees C)
T_{AE} = Ambient temperature, nonoperating (in degrees C)
CR = Cycling rate (the number of power cycles per year to which the system is exposed). In this case, it is assumed that the system transitions from a nonoperating environment to an operating environment at the same time that the power is applied.

217Plus™ Thyristor Failure Rate Model

The failure rate equation for thyristors [Reference 7] is:

$$\lambda_P = \pi_G(\lambda_{OB}\pi_{DCO}\pi_{TO} + \lambda_{EB}\pi_{DCN}\pi_{TE} + \lambda_{TCB}\pi_{CR}\pi_{DT}) + \lambda_{SJB}\pi_{SJDT} + \lambda_{IND}$$

λ_P = Predicted failure rate, failures per million calendar hours
π_G = Reliability growth failure rate multiplier

$$\pi_G = e^{(-\beta(Y-1993))}$$

β = *Growth constant. Function of thyristor type (see Table 2).*
λ_{OB} = Base failure rate, operating (see Table 2)
π_{DCO} = Failure rate multiplier for duty cycle, operating

$$\pi_{DCO} = \frac{DC}{DC_{1op}}$$

DC_{1op} = Constant. Function of thyristor type (see Table 2)
π_{TO} = Failure rate multiplier for temperature, operating

$$\pi_{TO} = e^{\left(\frac{-Ea_{op}}{0.00008617}\left(\frac{1}{T_{AO}+T_R+273}-\frac{1}{298}\right)\right)}$$

Ea_{op} = *Activation energy, operating. Function of thyristor type (see Table 2).*
T_R = *The junction temperature rise above the ambient operating temperature (T_{AO}). The junction temperature is, therefore, $T_{AO}+T_R$. T_R can be calculated in several ways:*

$T_{Rdefault}$ = Default temperature rise (see Table 2)

T_R = Actual temperature rise, if known

$T_R = \Theta_{JA} * P$
where Θ_{JA} is the junction-to-ambient thermal impedance and P is the power dissipated by the transistor

$T_R = \Theta_{JC} * P$
where Θ_{JC} is the junction-to-case thermal impedance and P is the power dissipated by the transistor

If this option is used, then T_{AO} should be replaced by T_C, the component case temperature, in the equation for π_{TO}

$T_R = \Delta T * S$
where ΔT is the difference in junction temperature between no power dissipated and full rated power dissipated, and S is the stress ratio and is equal to the actual forward current divided by the rated forward current

π_S = Failure rate multiplier stress

$$\pi_S = \frac{(V_S)^{1.9}}{0.26}$$

$$V_S = \frac{Voltage_{Applied-blocking}}{Voltage_{Rated-blocking}}$$

Default V_S = *Constant. Function of thyristor type (see Table 2)*
λ_{EB} = Base failure rate, environmental (see Table 2)
π_{DCN} = Failure rate multiplier, duty cycle – nonoperating

$$\pi_{DCN} = \frac{1-DC}{DC_{1nonop}}$$

DC_{1nonop} = Constant. Function of thyristor type (see Table 2)

π_{TE} = Failure rate multiplier, temperature – environment

$$\pi_{TE} = e^{\left(\frac{-Ea_{nonop}}{0.00008617}\left(\frac{1}{T_{AE}+273}-\frac{1}{298}\right)\right)}$$

Ea_{nonop} = Activation energy, nonoperating. Function of thyristor type (see Table 2)

λ_{TCB} = Base failure rate, temperature cycling (see Table 2)

π_{CR} = Failure rate multiplier, cycling rate

$$\pi_{CR} = \frac{CR}{CR_1}$$

CR_1 = Constant. Function of thyristor type (see Table 2)

π_{DT} = Failure rate multiplier, delta temperature

$$\pi_{DT} = \left(\frac{T_{AO}+T_R-T_{AE}}{DT_1}\right)^2$$

DT_1 = Constant. Function of thyristor type (see Table 2)

λ_{SJB} = Base failure rate, solder joint (see Table 2)

π_{SJDT} = Failure rate multiplier, solder joint delta temperature:

$$\pi_{SJDT} = \left(\frac{T_{AO}+T_R-T_{AE}}{44}\right)^{2.26}$$

λ_{IND} = Failure rate, induced (see Table 2)

As with the Transistor model, the environment-type and equipment-dependent default values for DC, TAO, TAE and CR were previously presented in Reference 1.

Example Calculation

What is the predicted failure rate of a field effect, high frequency microwave transistor manufactured in 2006. The transistor operates in a "Ground, Mobile, Heavy-wheeled" vehicle with an assumed operating temperature of 55°C, a dormant temperature of 14°C and a relative humidity of 40%. The temperature rise of the FET is unknown. The operating profile of the equipment is typical of military ground equipment, with a duty cycle of 45% and a cycling rate of 263 cycles per year.

The failure rate equation for a transistor [Reference 7] is:

$$\lambda_P = \pi_G\left(\lambda_{OB}\pi_{DCO}\pi_{TO} + \lambda_{EB}\pi_{DCN}\pi_{TE} + \lambda_{TCB}\pi_{CR}\pi_{DT}\right) + \lambda_{SJB}\pi_{SJDT} + \lambda_{IND}$$

where,

$$\pi_G = e^{(-\beta(Y-1993))} = 0.005736$$

where β = 0.397 (from Table 1) and Y = 2006 (given)

λ_{OB} = 0.001049 (from Table 1)

$$\pi_{DCO} = \frac{DC}{DC_{1op}} = 1.966$$

DC = 0.45 (given as 45%)

DC_{1op} = 0.23 (from Table 1)

$$\pi_{TO} = e^{\left(\frac{-Ea_{op}}{0.00008617}\left(\frac{1}{T_{AO}+T_R+273}-\frac{1}{298}\right)\right)} = 6.090$$

Ea_{op} = 0.20 (from Table 1)

T_{AO} = 55 (given)

$T_{Rdefault}$ = 60 (from Table 1)

π_S = 1 (Field effect transistor)

λ_{EB} = 0.0004674 (from Table 1)

$$\pi_{DCN} = \frac{1-DC}{DC_{1nonop}} = 0.7143$$

DC = 0.45 (given as 45%)

DC_{1nonop} = 0.77 (from Table 1)

$$\pi_{TE} = e^{\left(\frac{-Ea_{nonop}}{0.00008617}\left(\frac{1}{T_{AE}+273}-\frac{1}{298}\right)\right)} = 0.6390$$

Ea_{nonop} = 0.30 (from Table 1)

T_{AE} = 14 (given)

Table 2: Thyristor Parameters

Part Type	λ_{OB}	λ_{EB}	λ_{TCB}	λ_{IND}	λ_{SJB}	β	DC_{1op}	Ea_{op}	$T_{Rdefault}$	$V_{Sdefault}$	DC_{1nonop}	Ea_{nonop}	CR_1	DT_1
General	0.000393	0.004602	0.001756	0.01219	.00087	0.2	0.26	0.4	60	.37	0.74	0.4	508.77	73
SCR	0.000324	0.001011	0.00203	0.02001	.00087	0.2	0.26	0.4	60	.37	0.74	0.4	508.77	73
Triac	0.000576	0.007286	0.00199	0.01636	.00087	0.2	0.26	0.4	60	.37	0.74	0.4	508.77	73

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λ_{TCB} = 0.000225 (from Table 1)

$$\pi_{CR} = \frac{CR}{CR_1} = 0.3486$$

CR = 263 (given)
CR_1 = 754.38 (from Table 1)

$$\pi_{DT} = \left(\frac{T_{AO} + T_R - T_{AE}}{DT_1}\right)^2 = 1.594$$

T_{AO} = 55 (given)
$T_{Rdefault}$ = 60 (from Table 1)
T_{AE} = 14 (given)
DT_1 = 80 (from Table 1)

λ_{SJB} = 0.0015 (see Table 1)

π_{SJDT} = Failure rate multiplier, solder joint delta temperature:

$$\pi_{SJDT} = \left(\frac{T_{AO} + T_R - T_{AE}}{44}\right)^{2.26} = 6.540$$

T_{AO} = 55 (given)
$T_{Rdefault}$ = 60 (from Table 1)
T_{AE} = 14 (given)

λ_{IND} = 0.04541 (from Table 1)

λ_p = (0.005736)((0.001049)(1.966)(6.090)(1)+(0.0004674)(0.7143)(0.6390)+(0.000225)(0.3486)(1.594))+0.0015)(6.540)+(0.04541)

λ_p = 0.05529 f/10^6 calendar hours

Next Issue

The next issue of the RIAC Journal (4th Quarter 2008) will present the 217Plus™ software failure rate model in more detail.

References:

1. "An Introduction to the RIAC 217Plus™ Component Failure Rate Models", Journal of the Reliability Information Analysis Center, First Quarter 2007, available for PDF download from the RIAC at http://theRIAC.org
2. "The 217Plus™ Capacitor and Diode Failure Rate Models", Journal of the Reliability Information Analysis Center, Second Quarter 2007, available for PDF download from the RIAC at http://theRIAC.org
3. "The 217Plus™ Integrated Circuit and Inductor Failure Rate Models", Journal of the Reliability Information Analysis Center, Third Quarter 2007, available for PDF download from the RIAC at http://theRIAC.org
4. "The 217Plus™ Transformer and Optoelectronic Device Failure Rate Models", Journal of the Reliability Information Analysis Center, Fourth Quarter 2007, available for PDF download from the RIAC at http://theRIAC.org
5. "The 217Plus™ Switch and Relay Failure Rate Models", Journal of the Reliability Information Analysis Center, First Quarter 2008, available for PDF download from the RIAC at http://theRIAC.org
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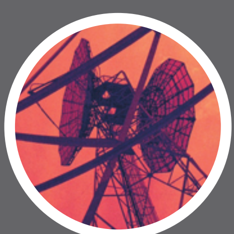
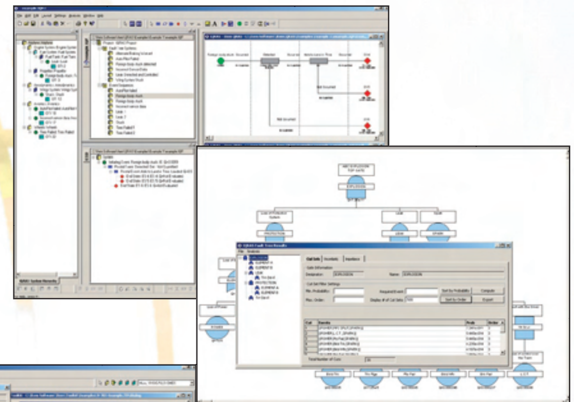
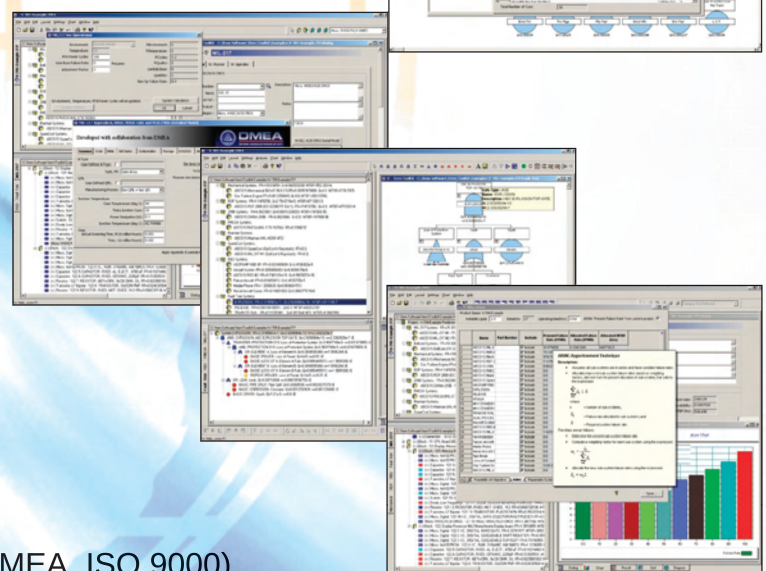
7. Denson, W.K., "Handbook of 217Plus™ Reliability Prediction Models", Reliability Information Analysis Center (RIAC), 26 May 2006, ISBN 1-933904-02-X
8. "An Overview of the 217Plus™ System Reliability Assessment Methodology", Journal of the Reliability Information Analysis Center, Fourth Quarter 2006, available for PDF download from the RIAC at http://theRIAC.org







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Contact: www.aiaa.org/content.cfm?pageid=230&lumeetingid=1868&viewcon=overview

IEEE GLOBECOM 2008 // New Orleans, LA

November 30, 2008 thru December 4, 2008
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