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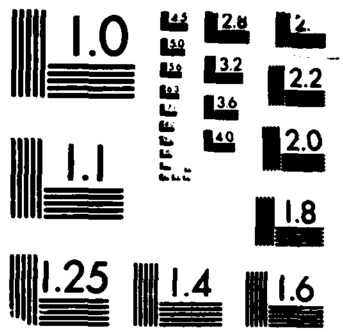

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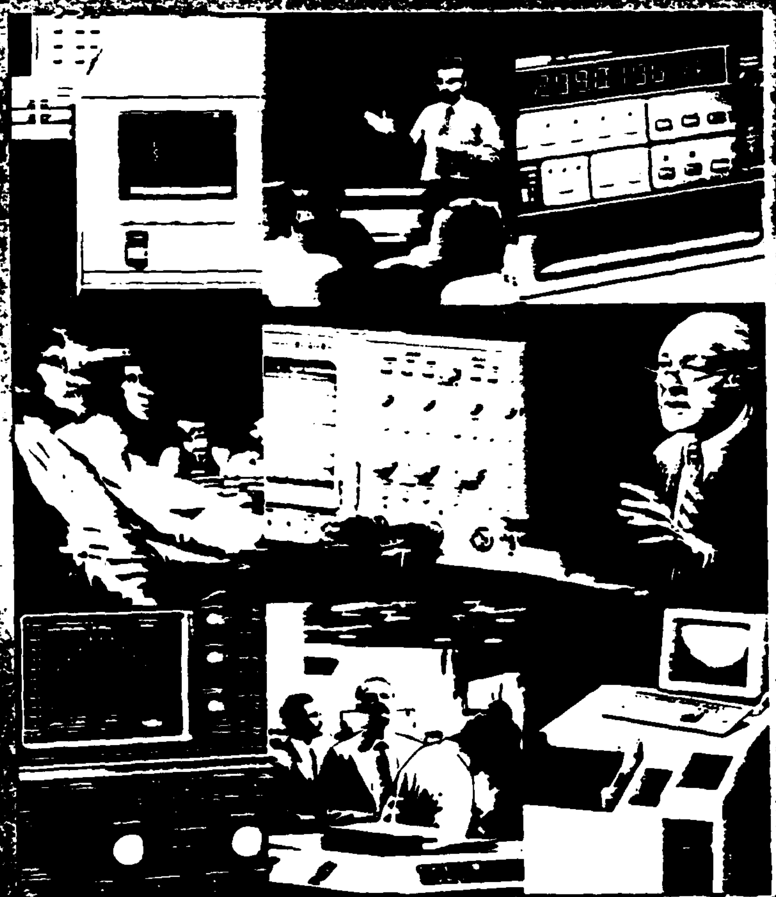

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THE MANY METHODS TO MEASURE TESTABILITY: A HORROR STORY

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ABSTRACT

The author has personally modeled designs varying from a Small Scale Integration (SSI) printed circuit board (PCB) up to a modern tank Fire Control System (FCS) of over 20 boxes using over a dozen Testability Figure of Merit (TFOM) tools. These various algorithms used a total of 70 different outputs that were intended to measure the TFOM inherent for a particular design. This paper will first review and categorize all of these TFOM values. Next, will be an attempt to lay the groundwork necessary to figure out if the optimum TFOM should be "one magic number" or several unique numbers. And finally, if several, what could they be ?

TFOM TOOLS

The variety of TFOM tools provide testability output measures differing from one number, up to a maximum of 24 measures. Table 1 summarizes the tools used by the author, with the number of measures listed for each. The three Sandia Controllability Observability Analysis Program (SCOAP) type TFOM tool outputs are broken into controllability (CO) and observability (OBS) of "one" and "zero" for sequential and combinational circuits, which is five or six different TFOM values. When this breakdown of CO and OBS is followed, it drives the total TFOM output number up to 84. Some TFOM tool outputs include other information such as fault isolation or dependency flow charts which are very useful, but not suitable as candidates for TFOM measure values. It is not the intent to compare the 13 TFOM tools to each other, but only to review all TFOM outputs as a database. Therefore there will be no correlation of the TFOM tool output measures to the parent TFOM tool(s) that they came from, although some are unique to one TFOM tool. Table 1 only indicates the tip of the TFOM measure forest.

THE TFOM FOREST

The first step is to list each of the testability measures from every tool. This will result in a summation of possible test measures that need to be reviewed to determine the optimum candidates for the best of the group. To avoid needless repetition and make make an understandable and manageable table, two liberties were taken. Seven items that appear more than once shall be listed only one time at the top, and CO and OBS shall be listed without all of the sequential and combinational "one" and "zero" variations. The resulting 49 measures are shown in Table

2. First, 70 of the output measures have been listed from all 13 TFOM tools. Duplicate or redundant figures are noted in order to reduce the total number in Table 2 down to 49 unique TFOMs.

THE TFOM TREES

The seven values that are used by more than one TFOM tool are listed in Table 2, along with the number of times that each appeared. Logically, it would seem that the more often that a particular output was used by various algorithms, the stronger its chances of being a valuable TFOM candidate. This may not necessarily be true. Ambiguity group size leads with seven occurrances. Next in number is recommended test point locations, with five times. Next in useage are feedback loop report and list of components with four each. Three measures are tied with three occurrances each. These are observability, controllability, and inherent testability figure of merit, or the "one value FOM". Unnecessary test point locations are an output two times. Finally, there are 48 other TFOM output results that appear only one time.

Next, the remaining 49 total unique outputs will be subjectively categorized as to whether they are potential strong "FOM number" candidates. These will be prime candidates under consideration as the "one magic number". These would be of most value to a buyer, such as the government, who demands a simplistic and easily specified desired level of testability. This selection is admittedly subjective, but the first cut of candidates for one FOM are shown in column two of Table 2. All occurrances of observability, controllability, and FOM, as well as three of the seven ambiguity group types were selected. Additionally, seven other one-time outputs are potentially good FOMs. This results in a total of 11 attractive single TFOM nominees.

The third column of the table shows output lists, rather than single numbers or values. These lists are of great value to the designer, but being lists, cannot be considered for "one number" FOM. Frequently these lists clarify or detail related FOM numbers, such as a list of items in an ambiguity group or list of BIT candidate sites. In fact those two lists accounted for nine occurrances in the first duplication elimination task. Additionally four of the seven ambiguity group examples were lists.

The last column in Table 2 is all of the other remaining TFOM values. These may be lists or single numbers that have some value regarding the design, but appear to be of less importance or less critical than the TFOMs previously noted in the second and third columns. This final step is hard to do, and it would be much easier to leave a majority of the TFOM outputs in the other two columns. However, such an approach would not make the needed progress toward the important goal of reducing the present TFOM forest. The current 49 TFOMs that a user is faced with is overwhelming and confusing. These values will continue to multiply as more TFOM and Design For Test (DFT) tools become available. System buyers who must have satisfactory and meaningful specifications of testability as targets for designs, need a succinct, useful and optimum TFOM criteria.

ONE MAGIC NUMBER OR SEVERAL NUMBERS

Finally, a close scrutiny of the strong TFOM candidates is required. This gets into an area potentially as volatile as politics or religion. That is the pros and cons of one number versus several numbers as a design TFOM. This is followed immediately by the decision as to which one number is the magic testability holy grail. This issue is potentially so controversial , that the author purposefully avoided it while doing dozens of TFOM evaluations on three benchmark designs. It would not serve the cause of testability to get into a dog fight over the "one acceptable FOM" and stall utilizing all of the assets available. Curiosity drove to the making of a list of all TFOM outputs personally used over the last few years. This list of 69 seems to force test professionals to finally face this issue head on in a positive dialogue and attitude. Testability obviously has many features and effects that can be noted and measured or listed, so it seems overly simplistic to assign only one "magic number" as a viable design goal. Different design technologies such as digital, analog, machanical or hybrid do have their own unique TFOM differences which one number could not possibly wrap its arms around. Possibilities to pursue could include different TFOM criteria for each technology, or the summing of several important TFOM values into one number.

PICKING THE BEST TFOM TREES

Referring back to the initial high repeater items as potential magic FOM nominees, it turned out that five of the eight ambiguity group items are lists, as were the next two most numerous items, test points and feedback loops. So it turns out that the three big repeaters are not possible FOM type values. Selection of a *single value such as controllability*, observability, or ambiguity group size would overlook other critical DFT problem areas. A problem with currently available single FOM outputs are questions on their objectivity, and what do they really say or prove ? One solution to the quandary of several good measures that cover the various and differing areas of DFT concern, is to sum several into one mean or average value. That sum value could be a TFOM goal of known meaning and discipline.

TEST PROGRAM SET/SYSTEM MEASURES

Long respected TFOMs of a sort have been the Test Program Set requirements and system design specs for percent of coverage and percent of ambiguity group sizes allowed. MIL-STD-2077A specifies general requirements for test program sets. One good measure in 2077 is Test Program Comprehension (TPC), which is the ratio between the number of faults detected and the total number of faults. The MIL-STD states TPC will be a minimum fault detection of 95 percent. Another MIL-STD TPS measure is time to isolate (TTI) for the worst case logic chain of each diagnostic branch. Although TPC or maximum logic chain TTI are not listed among the 69 TFOM tool outputs, analagous values appear once for each. System fault isolation requirements for specified ambiguity group size to a percent of faults are a common system design parameter. MIL-STD-470 Maintenance Demonstration (M-Demo) analyzes for design fault isolation capability, but no parameters are given. The ambiguity group isolation percent criteria are not stated in any MIL-STD, but are common design specifications.

It is surprising that these TPS or system specification type values were very rare in the 69 TFOM values. Percent of signal coverage, Mean Time to Isolate (MTTI), and non-detect list, which are common TPS or system specs, each appeared only one in the total of 69 items. In fact, the MTTI could conceivably have been included in the recurring group under two or three occurrances. One tool had MTTI stand-alone, another coupled MTTI with MTTR, and a third tool had average number of tests to ilolate, which could be converted to MTTI in minutes. To keep a standard methodology for exact match-up of values before considering duplication, these three outputs were not interpreted as being the same. Objective process is a difficult discipline in such a subjective and volatile area.

OPTIMUM TFOM MEASURE CANDIDATES

Although it is not the intent of the author to add more FOMs to the initial list of 69, it would seem that the time-proven values used in TPS or system design specs are good TFOM candidates. Prime nominees for quality TFOM factors are illustrated in Table 3, with TFOM, TPS, and system measures listed for correlation. Note that only ambiguity group size and percent of coverage are used in all three TFOM measure source columns. The summing or averaging of several of the better TFOMs noted here, would be a good basis for a meaningful and useful FOM design goal. It would also help link the different test design disciplines into some common terms and measures, which is a good goal all by itself.

CONCLUSIONS

TFOM tool vendors can no longer continue to make up their own unique TFOMs with no regard for the need of standard design benchmarks, which the designer and design buyer need in their designs. Other contractual "ilities" such as reliability or maintainability have standard constant measures that everyone agrees upon and comply with. Until testability does the same thing, it cannot be designed or measured in an objective and disciplined manner. In most cases, the design, TPS, and system spec are all measuring the same thing by different criteria. For example, a Computer Aided Design (CAD) workstation with SCOAP software will seek observability and controllability, then the

TPS has different MIL-STD test coverage specs, and the final system has still different MTTI and availability goals to meet.

The proper use of any of the available TFOM tools by a designer will undoubtedly improve the testability of a design and reduce test program costs and fault isolation time. It is also probable, that until this TFOM question is faced head on, TFOM tools will continue to crank out additional dozens of new and different unique numbers and lists. Most tragically of all, designs of doubtful testability will continue to be bought off by the government, company, or contractor until meaningful and agreed upon TFOM measures are adopted and used by designers.

TOOL	NUMBER OF OUTPUTS
MIL-STD-2165	ONE
RADC LIST	ONE
ITFOM	ONE
LONGENDORFER	FOUR
LOGMOD	FIVE
CALMA COPTR	FIVE
SCOAP	SIX
DAISY DTA	SIX
ASTEP	SIX
ACE	EIGHT
CAFIT	EIGHT
IN-ATE	NINE
STAMP	TWENTY FOUR

Table 1. Overview of 13 TFOM tools with the number of test measure outputs of each.

MEASURE	USED IN TFOM	USED IN TPS	DESIGN SPEC
CONTROLLABILITY	YES	NO	NO
OBSERVABILITY	YES	NO	NO
AMBIGUITY GROUP	YES	YES	YES
ONE NUMBER FOM	YES	NO	YES
PERCENT OF COVERAGE	YES	YES	YES
MEAN TTI (MTTI)	YES	NO	YES
NON-DETECTS	YES	YES	NO
MAXIMUM TTI	NO	YES	NO
T.P. COMPREHENSION	NO	YES	NO

Table 3. Optimum TFOM measures which come from TFOM tools, TPS acceptance specs, or system design specs.

TFOM OUTPUT	USED	BEST FOM	BEST LIST	OTHER
AMBIGUITY GROUP SIZE	8	3	5	
TEST POINT SITE HEIRARCHY	5		5	
FEEDBACK LOOPS	4		4	
OBSERVABILITY	3	3		
CONTROLLABILITY	3	3		
INHERENT FOM	3	3		
UNUSED TEST POINTS	2		2	
ITEM INVOLVEMENT RATIO	1			1
MTTI/MTTR	1			1
MEAN REPLACEMENT LIST SIZE	1	1		
MEAN PRIORITIZED REPLACE POSITION	1		1	
PROBABILITY OF FAULT DETECTION	1	1		
MTTI	1	1		
DETECTED FAILURE RATE	1		1	
BASIC TEST PROGRAM	1		1	
ATLAS TEST PROGRAM	1		1	
EDIF FILE	1			1
TEST STRATEGY FLOWCHART	1		1	
RTOK FREQUENCY	1			1
DIAGNOSIS AVERAGE COST	1		1	
AVERAGE REPLACEMENT COST	1		1	
ISOLATION LEVEL	1			1
TEST LEVERAGE (TL)	1			1
NON-REDUNDANT	1			1
TEST UNIQUENESS	1			1
TEST FEEDBACK DOMINANCE	1			1
COMPONENT FEEDBACK DOMINANCE	1			1
NONDETECT PERCENT	1	1		
HIDDEN FAILURE MEASURE (HFM)	1			1
INPUT MODIFIED HFM	1			1
PERCENT HFM (PHFM)	1			1
INPUT MODIFIED PHFM	1			1
FALSE FAILURE MEASURE (FFM)	1			1
INPUT-MODIFIED FFM	1			1
DEPENDENCY	1			1
TEST INTERDEPENDENCY	1			1
TEST DEPENDENCY	1			1
FALSE ALARM TOLERANCE	1			1
THEORETICAL MIN/MAX TL	1			1
EXTERNAL DEPENDENCY	1			1
EXCESS TEST MEASURE	1			1
NEGATIVE RECONVERGENCE	1			1
LOGIC REDUNDANCY	1			1
DEVICE SIGNAL COVERAGE	1			1
TPS FLOWCHART	1		1	
AVERAGE NUMBER TTI	1	1		
TEST SIGNAL COST CONTRIBUTION	1			1
TEST POINT COST CONTRIBUTION	1			1
BLOCK TFOM	1			1

Table 2. Summary of 70 TFOM outputs from 13 tools, with values and lists categorized and prioritized.

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