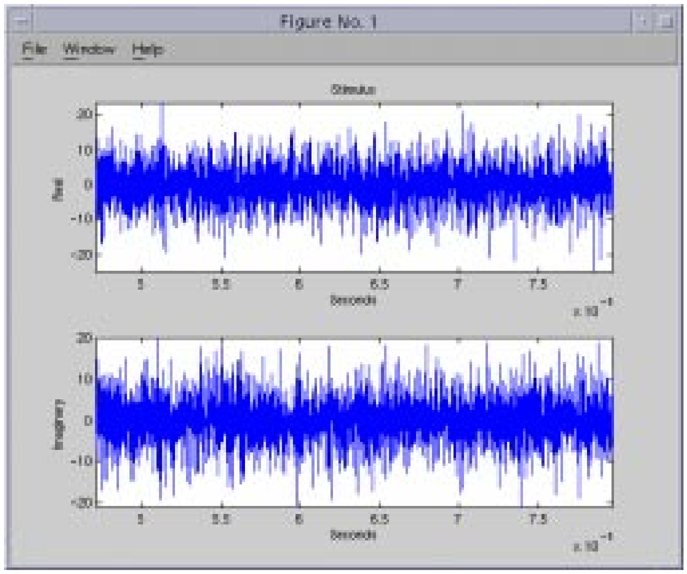


Figure 6.10 Test Vector Generated in Example 4

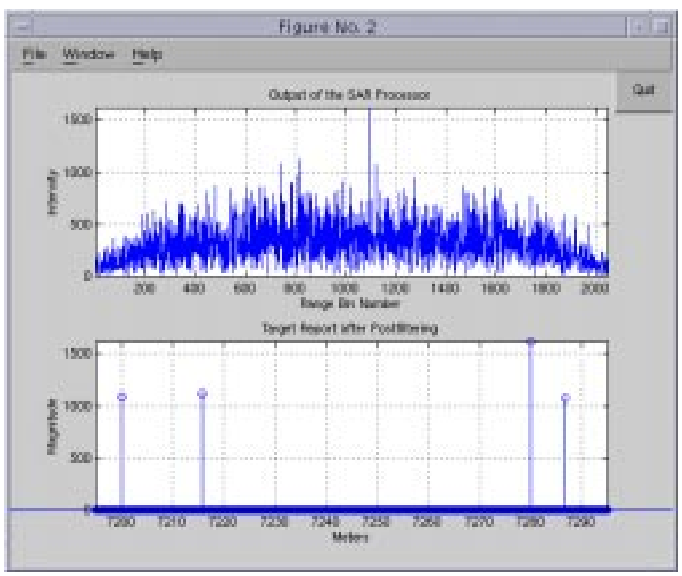
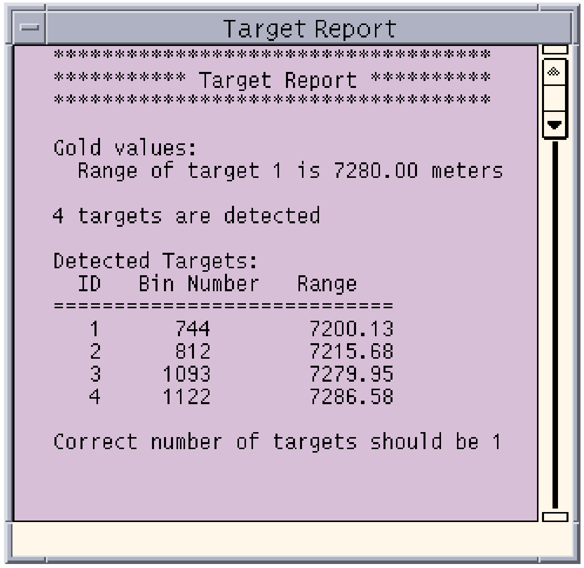


Figure 6.11 Range Profile and Reported Targets in Example 4



```
Target Report
*************************************
*********** Target Report **********
*************************************

Gold values:
  Range of target 1 is 7280.00 meters

4 targets are detected

Detected Targets:
  ID   Bin Number   Range
============================
   1      744        7200.13
   2      812        7215.68
   3     1093        7279.95
   4     1122        7286.58

Correct number of targets should be 1
```

Figure 6.12 Target Report in Example 4

Example 5

This example demonstrates the capability that the Test Planning Graphical User Interface provides to configure the model under test. The model under test is a two-dimensional SAR model which performs video to baseband I/Q conversion, range compression processing, and azimuth compression processing. The user is allowed to configure an internal finite impulse response (FIR) filter of the MUT by providing a set of filter coefficients. The test vector is a 16×16 array which represents the radar return from 16 chirp pulses with 16 samples per pulse. The MUT response is a 16×16 SAR image with axes indicating the range and azimuth directions, and amplitude indicating the intensity of the target return. The comparator computes the signal to error ratio (SER), i.e., the power ratio of the MUT response and the error. The gold image and the output image are automatically displayed once simulation is finished. Figure 6.13 shows the gold SAR image which is provided by MIT Lincoln Lab. Figure 6.14 shows the SAR image produced by the properly configured MUT. The error is insignificant, with a high SER of 101.2 dB. Figure 6.15 shows the response of the MUT whose FIR coefficients are misconfigured by a set of random numbers, with a low SER of only 0.6833 dB.

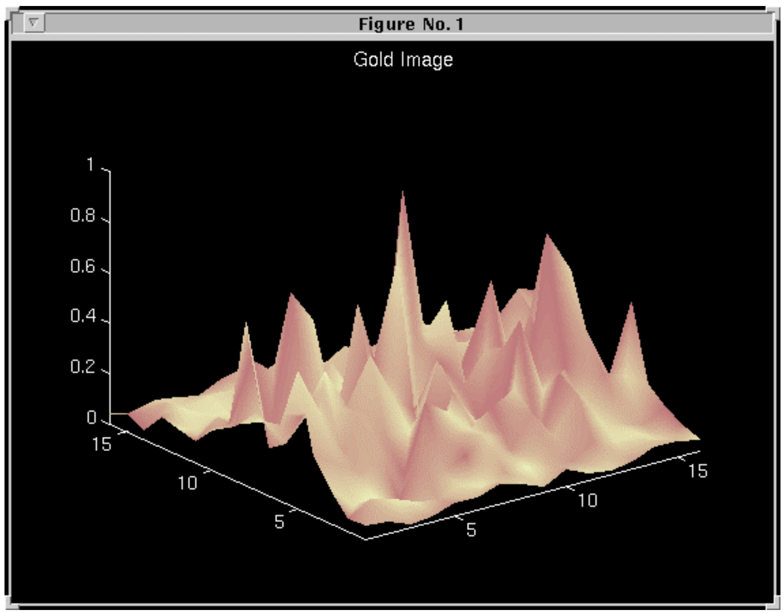


Figure 6.13 Gold Image in Example 5

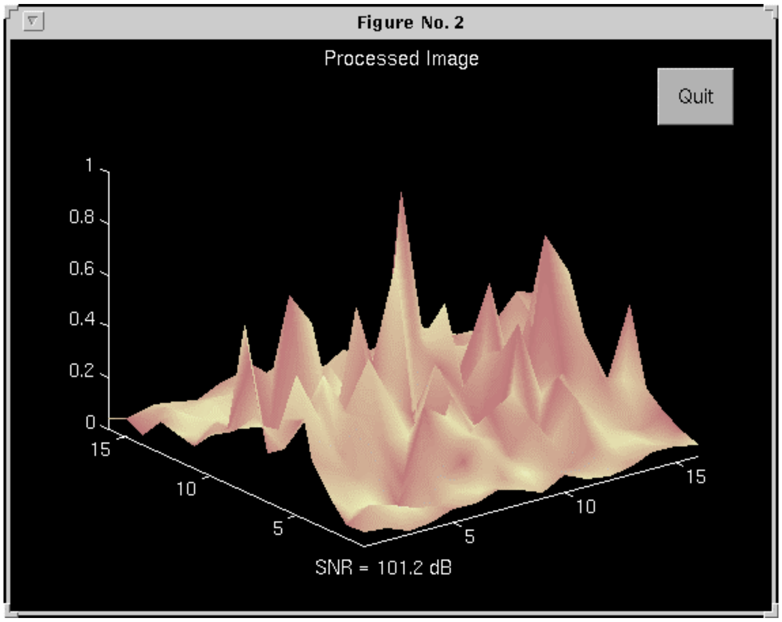


Figure 6.14 SAR Image of Properly Configured MUT

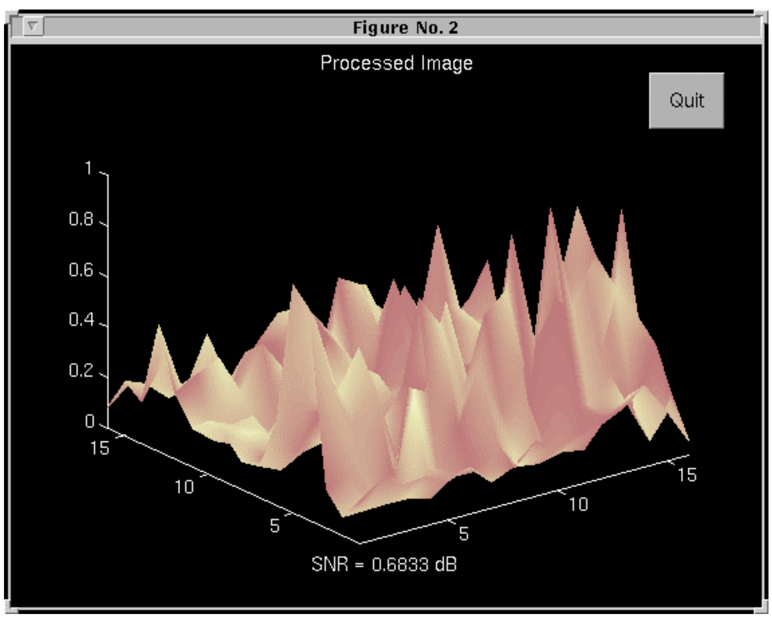


Figure 6.15 SAR Image of Misconfigured MUT

6.2 Results of SAR Test Plan

The SAR model has been tested using the test planning system according to the test plan discussed in Section 5.6. This section details the results of the execution of the SAR test plan under the test plan driven mode of the TPGUI. The SAR goal tree implemented in the goal tree editor has been displayed in Figure 4.16. Figure 4.5 has shown the base window of the TPGUI under the test plan driven mode.

6.2.1 Subgoal G_1: Footprint Location

The footprint location subgoal G_1 validates the range compression processing capability of the SAR MUT. It is composed of two primitive goals G_{11} and G_{12}.

Primitive Goal G_{11}: Footprint Range Bin

The test group TG_{11} varies the target location to see whether the MUT processes the accurate range bin number of the footprint. The number of tests is set to 9. The results are summarized in Table 6.1, which shows that the MUT detects the footprint range bin number correctly in all these tests.

Primitive Goal G_{12}: Footprint Range Error

The footprint range error goal G_{12} is similar to the test goal G_{11} except that it uses a different comparator parameter. Specifically, the detected range in meters is compared instead of the detected range bin number. It reuses the tests generated in the test group TG_{11}. The results show that the MUT passes all 9 tests with mean squared error 0.09 meters computed across these tests. The simulation results are also summarized in Table 6.1.

Table 6.1 Results of Goal G_{11} and G_{12}

Test No.	Test Group TG_{11}			Test Group TG_{12}' (in meters)			
	Gold Range Bin	**Detected Range Bin**	**Result**	**Gold Range**	**Detected Range**	**Error**	**Result**
T_{111}	185	185	pass	7072.50	7072.59	0.09	pass
T_{112}	390	390	pass	7119.38	7119.47	0.09	pass
T_{113}	595	595	pass	7166.26	7166.36	0.10	pass
T_{114}	800	800	pass	7213.12	7213.24	0.12	pass
T_{115}	1004	1004	pass	7260.00	7259.90	-0.10	pass
T_{116}	1209	1209	pass	7306.88	7306.79	-0.09	pass
T_{117}	1414	1414	pass	7353.75	7353.67	-0.08	pass
T_{118}	1619	1619	pass	7400.62	7400.56	-0.06	pass
T_{119}	1824	1824	pass	7447.50	7447.44	-0.06	pass

6.2.2 Subgoal G_{21}: Range Resolution

The range resolution subgoal G_{21} evaluates the range resolution of the SAR MUT. It applies the geometric-binary strategy to search for the nearest and the farthest possible target locations that map to the same range bin. The difference between these two locations is then the range resolution of the MUT. This subgoal is decomposed into two primitive goals G_{211} and G_{212}. The test T_{115} in the test group TG_{11} that maps the target at 7,260 meters to the range bin number 1,004 is utilized as a starting point. Specifically, starting at the target location of 7,260 meters, the primitive goal G_{211} applies the test group TG_{211} to search downward for the nearest location mapping to the range bin number 1,004 with initial increment 0.01 meters and precision 0.01 meters. Also, starting at the target location of 7,260 meters, the primitive goal G_{212} applies the test group TG_{212} to search upward for the farthest location mapping to the range bin number 1,004 with the same initial increment and precision setting as in TG_{211}. Both test groups use the range bin number as comparator parameter. Both test groups combine to finish in 12 iterations of simulation, and the results show that the near bound falls in the range (7,259.79 meters, 7,259.80 meters) and the far bound falls in the range (7,260.01 meters, 7,260.02 meters). Thus, the resultant range resolution falls in the range (0.21 meters and 0.23 meters), which meets the ideal value 0.22871 meters given in the SAR specification [9]. Table 6.2 summarizes the simulation results for the test groups TG_{211} and TG_{211}.

Table 6.2 Results of TG_{211} and TG_{212}

Test Group	Search Strategy	Test No.	Target Range	Detected Range Bin	Result
TG_{211}	Geometric	T_{2111}	7259.99	1004	pass
		T_{2112}	7259.98	1004	pass
		T_{2113}	7259.96	1004	pass
		T_{2114}	7259.92	1004	pass
		T_{2115}	7259.84	1004	pass
		T_{2116}	7259.68	1003	fail
	Binary	T_{2117}	7259.76	1003	fail
		T_{2118}	7259.80	1004	pass
		T_{2119}	7259.78	1003	fail
		$T_{211(10)}$	7259.79	1003	fail
TG_{212}	Geometric	T_{2121}	7260.01	1004	pass
		T_{2122}	7260.02	1005	fail

6.2.3 Subgoal G_{22}: Sensitivity to Noise

This subgoal searches for the maximum noise level that the MUT can tolerate for targets located in various places mapping to the same range bin. The adjustable requirement is the standard deviation of the Gaussian noise normalized to the amplitude of the transmitted radar signal. This goal consists of three primitive goals G_{221}, G_{222}, and G_{223}, where the target is placed, respectively, at the nearest point, midpoint, and farthest point that map to the same range bin. By utilizing the results obtained from the test goal G_{21}, the three chosen target locations are 7,259.79 meters, 7,259.90 meters, and 7,260.01 meters, one for each corresponding test group. The test groups TG_{221}, TG_{222}, and TG_{223} employ the geometric-binary search strategy with the initial noise level 1, the initial increment 2, and the precision 0.1, and use the target range in meters as the comparator parameter. The simulation results show that 9 tests are initiated for each test group, and the limiting values fall in the ranges (6.5625, 6.625), (6.5625, 6.625), and (6.5, 6.5625), respectively. A conservative conclusion drawn from these ranges is that the MUT can tolerate the Gaussian noise with standard deviation up to 6.5 times as large as the magnitude of the transmitted signal. Table 6.3 summarizes the simulation results from the generated target reports.

Table 6.3 Results of TG_{221}, TG_{222}, and TG_{223}

Test Group	Search Strategy	Test No.	Noise Level	No. of Detected Targets	Detected Range Error (meter)	Result
TG_{221}	Geometric	T_{2211}	1	1	-0.1	Pass
		T_{2212}	3	1	-0.1	Pass
		T_{2213}	7	3	N/A	Fail
	Binary	T_{2214}	5	1	-0.1	Pass
		T_{2215}	6	1	-0.1	Pass
		T_{2216}	6.5	1	-0.1	Pass
		T_{2217}	6.75	3	N/A	Fail
		T_{2218}	6.625	2	N/A	Fail
		T_{2219}	6.5625	1	-0.1	Pass
TG_{222}	Geometric	T_{2221}	1	1	0.1	Pass
		T_{2222}	3	1	0.1	Pass
		T_{2223}	7	3	N/A	Fail
	Binary	T_{2224}	5	1	0.1	Pass
		T_{2225}	6	1	0.1	Pass
		T_{2226}	6.5	1	0.1	Pass
		T_{2227}	6.75	3	N/A	Fail
		T_{2228}	6.625	2	N/A	Fail
		T_{2229}	6.5625	1	0.1	Pass
TG_{223}	Geometric	T_{2231}	1	1	-0.11	Pass
		T_{2232}	3	1	-0.11	Pass
		T_{2233}	7	3	N/A	Fail
	Binary	T_{2234}	5	1	-0.11	Pass
		T_{2235}	6	1	-0.11	Pass
		T_{2236}	6.5	1	0.12	Pass
		T_{2237}	6.75	3	N/A	Fail
		T_{2238}	6.625	2	N/A	Fail
		T_{2239}	6.5625	2	N/A	Fail

6.3 Quality Evaluation

The simulation results of the SAR test plan have been discussed in the previous sections. This section describes the results of evaluating the quality of the test set generated by simulating the SAR goal tree. All test groups using the file I/O strategy in the SAR goal tree are chosen for tree traversal so that the original test vectors are be replayed for the purpose of evaluation.

6.3.1 Completeness

As stated in Section 2.1, functional testing treats the MUT as a black box and may not test all parts of the model. To find out how complete the SAR model under test has been tested, VHDL statement coverage has been analyzed using Synopsys coverage utility against the test set. The analysis shows that 100% statement coverage has been achieved. In other words, all statements have been executed. Derived from the statement coverage, branch coverage against the test set is also 100%.

6.3.2 Effectiveness

Mutation analysis has been used to evaluate the effectiveness of the test set. Mutation testing is to software what fault analysis is to digital circuits in many respects

[64, 42]. It is a technique for evaluating the adequacy of the test set by examining the ability of the test set to differentiate between a correct program and an incorrect one [39, 40]. During mutation testing, small faults are deliberately introduced into the program by creating various versions of the program [65, 66]. These faulty programs, termed as mutants of the original, are executed against the test set. If a mutant is detected by a test case, it is said to be killed and the fault it comprises is detectable by the test set. If a mutant can not be killed by any test case in the test set, it is either functionally equivalent to the original program so that no test case can kill it, or it is killable but the test set is not sufficient to kill it.

In mutation testing the errors result from logical failures in a program rather than failures of physical components as in digital circuits [42]. Mutants are systematically constructed based on model perturbation by applying mutant operators to the original model [56, 31]. Exactly one fault is injected to obtain a mutant on the basis of the coupling effect, which means that complex faults are coupled to single faults in such a way that a test set detecting all single faults in a program will detect most complex faults [65].

The fault mappings [41, 30] listed in Table 6.4 have been applied to the SAR MUT, which limit the theoretically infinite number of possible mutants to a tractable size. Totally, 149 nonequivalent mutants are generated. A *mutation score*, analogous to the fault coverage in digital logic testing, is a number in the interval [0, 1] which is defined to the fraction of the nonequivalent mutants killed by the test set [42, 64]. The result of the mutation experiment is summarized in Table 6.5. Mutation analysis is first applied to the 149 generated mutants against the test group TG_{11}. The result shows that 114 mutants are killed by the test group TG_{11} and 35 mutants survive. Mutation analysis is applied again to the 35 remaining mutants against the test groups TG_{211} and TG_{212}, which combine to kill 4 mutants and leave 31 mutants alive. Finally, the Mutation analysis is applied again to the 35 remaining mutants against the test groups TG_{211} and TG_{212}, which combine to kill 4 mutants and leave 31 mutants alive. Finally, the 31 mutants are tested against the test groups TG_{221}, TG_{222}, and TG_{223}, which combine to kill 22 mutants and leave 22 mutants alive. Totally, 140 mutants are killed by the complete test set. In other words, the overall mutation score is 0.940 or 94.0%. The results of mutation analysis show that the test set generated in SAR goal tree is effective in fault detection.

Test set compaction has been applied to eliminate redundant tests in each test group using Quine-McCluskey's method [85, 86]. The results are summarized in Table 6.6, which shows that 3 tests in the test group TG_{11} are irredundant. Also, for the search test groups TG_{211}, TG_{212}, TG_{221}, TG_{222}, and TG_{223}, the test cases where the extreme values of the adjustable requirements are found are irredundant. This result verifies that the search strategies that explore the boundary value conditions in the output space are indeed effective.

Table 6.4 Fault Mappings

No.	Category	Fault Free	Faulty
1	Conditional	if …	if true
2		if …	if false
3		if …	if not (…)
4	Constant	C	C + 1
5		C	C - 1
6	Function Call	cos (A)	sin (A)
7	Numerical Operator	-A	A
8		A + B	A - B
9		A - B	A + B
10		A * B	A / B
11		A / B	A * B
12		A ** B	A * B
13	Relational Operator	A = B	A /= B
14		A <= B	A > B
15		A < B	A >= B
16		A > B	A < =B
17		A >= B	A < B
18	Logical Operator	A and B	A or B
19		A or B	A and B

Table 6.5 Results of Mutation Analysis

Test Goal Type	Confirmation	Search	
Test Group	TG_{11}	TG_{211},TG_{212}	TG_{221},TG_{222},TG_{223}
No. of Tested Mutants	149	35	31
No. of Surviving Mutants	35	31	9
No. of Killed Mutants	114	4	22
Accumulated No. of Killed Mutants	114	118	140
Accumulated Mutation Score	0.765	0.792	0.940

Table 6.6 Results of Test Set Compaction

Test Groups	**TG_{11}**	**TG_{211}**	**TG_{212}**	**TG_{221}**	**TG_{222}**	**TG_{223}**
Goal Type	Confirmation	Search	Search	Search	Search	Search
Irredundant Tests	T_{111}, T_{115}, T_{119}	T_{2118}	T_{2121}	T_{2219}	T_{2229}	T_{2236}