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A STRUCTURAL–TEMPORAL DIGITAL CORRELATION METHOD FOR DFT/ATPG FAULT LOCALIZATION

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Abstract

Modern Design-for-Test (DFT) verification produces heterogeneous digital diagnostic information, including ATPG fault reports, structural connectivity, scan-cell states, unknown-value propagation paths, and time-domain simulation waveforms. In this work, a structural-temporal digital correlation method is applied to DFT/ATPG fault localization in integrated circuits. The method combines fault information generated in Siemens EDA Tessent with structural observations from Tessent Visualizer and temporal measurements obtained from Synopsys Verdi waveforms. Diagnostic information is represented by a common set of spatial and temporal attributes and correlated to reduce the fault-candidate search space and trace a failure from its observation point toward its probable source. For Stuck-at, Transition Delay Fault (TDF), and X-propagation cases, the measurement protocol defines fault-specific observables together with candidate reduction (CR), localization efficiency (E_loc), diagnosis time (T_diag), and, when a baseline is available, diagnosis-time reduction (R_t). The measurement procedure treats DFT debugging as a digital measurement and information-processing problem and defines the quantities needed for repeatable evaluation.

Keywords: *Design-for-Test (DFT), Automatic Test Pattern Generation (ATPG), Fault Localization, Structural-Temporal Correlation, Digital Measurement, X-Propagation, Tessent, Verdi.*

INTRODUCTION

The continuous increase in integrated-circuit complexity makes manufacturing test, DFT verification, and failure diagnosis increasingly dependent on the processing of large volumes of digital information. Scan architectures and ATPG improve controllability and observability, but a failing pattern alone does not identify the physical or logical cause of the observed response. Practical diagnosis therefore requires correlation between fault reports, structural connectivity, logic states, clock and reset behavior, and simulation waveforms.

Recent research has addressed diagnosis through fault-candidate reduction [1], multi-channel scan data [2], graph-based delay-fault localization [3], and dedicated scan-chain diagnostic architectures [4]. Broader work also shows an increasing use of machine learning and data-driven processing in test and post-silicon diagnosis [5], while Transition Delay Fault (TDF) testing remains strongly dependent on launch/capture conditions and test-pattern quality [6]. These studies demonstrate that diagnostic performance depends not only on fault detection, but on how test information is represented, filtered, and correlated.

In practical debugging, the required evidence is usually distributed across ATPG reports, structural views, RTL/source-code context, and time-domain waveforms. In this work, these outputs are treated as complementary digital measurements rather than independent tool views. The diagnostic procedure uses a common representation and a deterministic correlation sequence to narrow the candidate set and localize the root cause.

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Here, ATPG fault information, structural connectivity, X-propagation data, and waveform timing information are combined in one fault-localization flow. The same flow defines a repeatable measurement protocol for Stuck-at, TDF, and X-propagation cases and uses three primary quantitative indicators: candidate reduction, localization efficiency, and diagnosis time. These indicators allow diagnostic runs to be compared across fault classes and design revisions without reducing the analysis to a tool-specific visual inspection.

DIGITAL DIAGNOSTIC METHOD

The workflow is based on Siemens EDA Tessent for DFT implementation, ATPG and fault information, Tessent Visualizer for structural tracing, and Synopsys Verdi for RTL/source-code and waveform analysis. The method does not depend on a single fault model; instead, it organizes the available diagnostic information into a common record D = [F, P, S, Xs, Op, L, t_div, N0, Ns, Nc, T_diag, CLK, RST], where F is the fault class, P is the failing pattern, S is the affected scan element or node, Xs is an identified source of an unknown value, Op is an observation point, L is the structural propagation depth, t_div is the first time-domain divergence, N0 is the initial ATPG candidate count, Ns is the count after structural filtering, Nc is the count after structural-temporal correlation, and T_diag is the measured diagnosis time. Fault-specific fields are added for TDF and X-propagation as described in the measurement protocol.

Stage 1 - fault extraction. The failing ATPG pattern and its initial candidate set are recorded. For each candidate, the fault type, affected node, expected response, and observation location are extracted. This establishes N_ATPG, the initial number of diagnostic candidates before structural or temporal filtering.

Stage 2 - structural localization. Structural tracing is used to determine whether a candidate lies on a causally valid path toward the observed failure. Multiplexers, scan cells, buffers, test-control logic, tie cells, and X-sources are followed from source to observation point. Candidates inconsistent with the observed connectivity are removed, producing N_struct. The number of logic levels L between the probable source and observation point is recorded as a structural measurement.

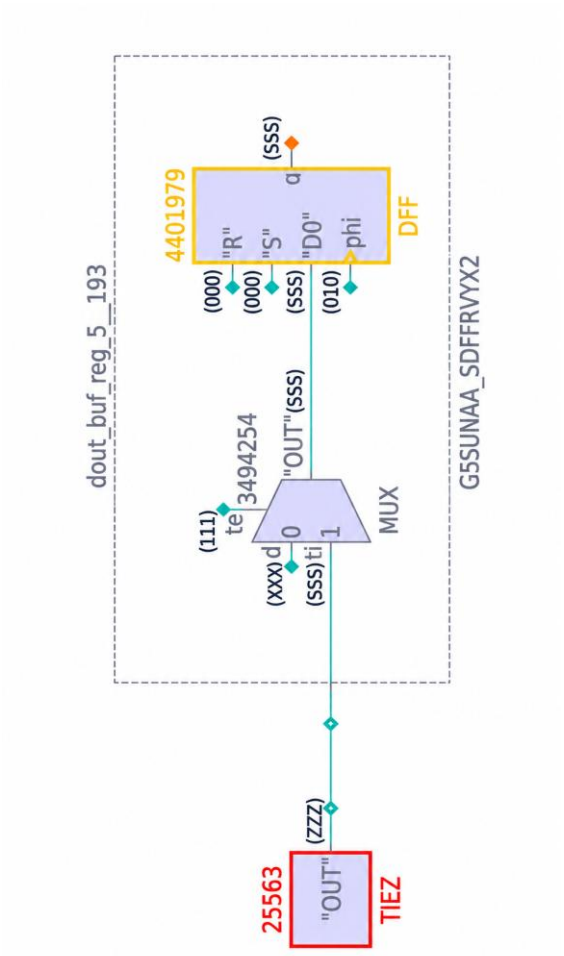


Fig. 1. *Structural propagation path from TIEZ through MUX to DFF.*

The example in Fig. 1 illustrates the spatial component of the method. The TIEZ -> MUX -> DFF path provides an explicit propagation chain that can be compared with the ATPG candidate location. This converts a visual inspection into a measurable structural relation: path membership, source-to-observation connectivity, and propagation depth.

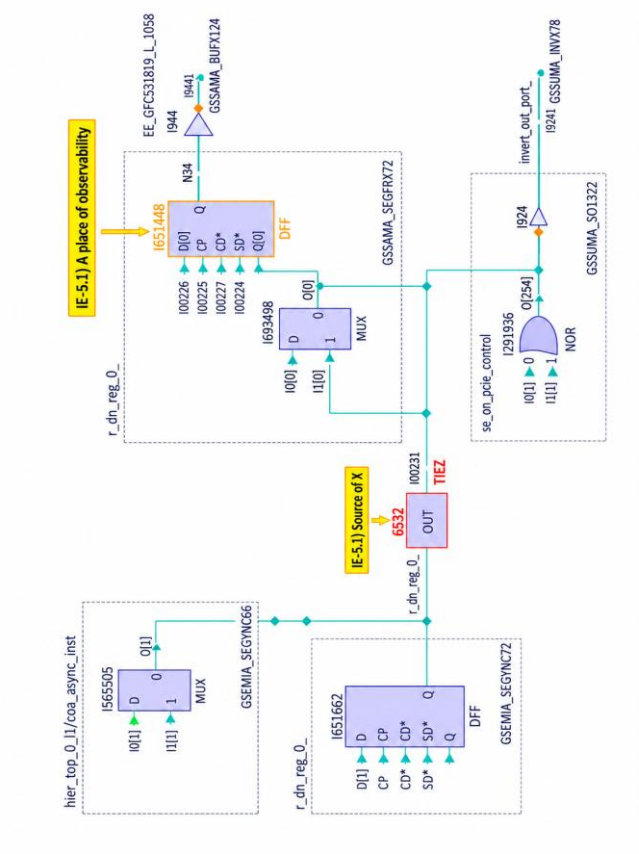


Fig. 2. *Identification of an X-source and an observation point during structural analysis.*

Figure 2 shows the complementary use of source and observation information for X-propagation analysis. Instead of treating an unknown value only as a waveform symptom, the method records its structural origin and the point at which it becomes diagnostically observable. This information is later correlated with the time-domain event.

Stage 3 - temporal correlation. The remaining structural candidates are examined in Verdi. The relevant clock, reset, scan-enable, pattern and data signals are aligned with the launch and capture sequence. The first divergence between expected and observed behavior is recorded as td. A candidate is retained only when the waveform event is temporally consistent with the structural propagation path, producing the final correlated candidate count N_corr.

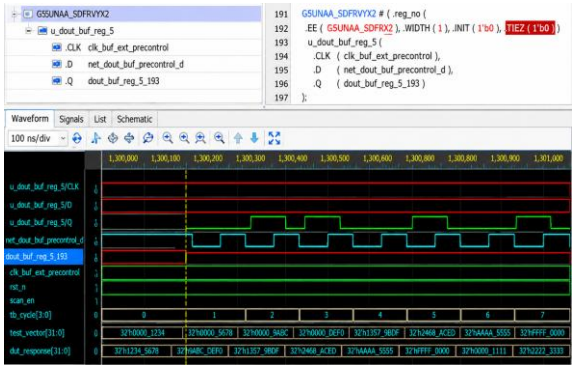


Fig. 3. *Waveform-based temporal analysis of DFT-related control and data signals.*

Stage 4 - root-cause decision. The structural and temporal measurements are evaluated together. A root-cause hypothesis is strengthened when the candidate belongs to the observed propagation cone, the source-to-observation path is valid, and the first waveform divergence occurs in a causally consistent interval. The method therefore combines spatial and temporal evidence rather than relying only on an ATPG failure report.

The available examples support three complementary observations. First, Fig. 1 provides an explicit structural path that can be measured in logic levels. Second, Fig. 2 identifies both the source of an unknown value and an observation point, allowing X-propagation to be represented as source/path/observation data. Third, Fig. 3 adds the temporal dimension needed to distinguish a structurally plausible candidate from a candidate whose behavior is inconsistent with the launch/capture, clock, reset, or test-control sequence. Together, these observations define the structural-temporal correlation used in the analysis.

The quantitative evaluation is performed with a fixed start/stop protocol. A diagnostic run starts when the failing ATPG pattern and its initial candidate list are available to the engineer and stops when a root cause is accepted after structural and temporal validation. Candidate counts are recorded at three points: N0 before correlation, Ns after structural filtering, and Nc after waveform correlation. Diagnosis time T_diag is

measured over the same interval. For operator-dependent timing, each case should be repeated three times and the median T_diag reported. A baseline run, if used, must apply the same start and stop conditions.

Stuck-at measurement. Record the fault polarity (SA0 or SA1), failing pattern/capture cycle, N0, Ns, Nc, source-to-observation logic depth L, the first mismatch cycle/time t_div, T_diag, and a validation flag V. V = 1 only when the final diagnosis matches a known/injected fault or a design condition independently verified in the netlist/RTL and waveform; otherwise V = 0.

TDF measurement. Record the transition class (slow-to-rise or slow-to-fall), launch cycle, capture cycle, launch-to-capture interval Delta_tLC, N0, Ns, Nc, L, t_div relative to the launch/capture event, T_diag, and V. This distinguishes a structurally plausible path from a candidate whose temporal behavior is inconsistent with the applied at-speed sequence.

X-propagation measurement. Record the identified X-source Xs, observation point Op, time of first X appearance t_X, X persistence Delta_tX, X-propagation depth L_X, number of affected observation points N_Xobs, N0, Ns, Nc, T_diag, and V. These values quantify not only where the unknown originates, but also how far and how long it contaminates the diagnostic response.

Table 1. *Fault-specific measurement protocol.*

Fault	Direct measurements	Indicators
Stuck-at	SA0/SA1; pattern/cycle; N0, Ns, Nc; L; t_div; T_diag; V	CR, E_loc, R_t
TDF	STR/STF; launch/capture; Delta_tLC; N0, Ns, Nc; L; t_div; T_diag; V	CR, E_loc, R_t
X-prop.	Xs, Op; t_X; Delta_tX; L_X; N_Xobs; N0, Ns, Nc; T_diag; V	CR, E_loc, R_t

Derived indicators. Candidate reduction is CR = (N0 - Nc) / N0 x 100%. A unique-correct flag U is set to 1 only when Nc = 1 and V = 1; otherwise U = 0. For a fault class containing n investigated cases, localization efficiency is E_loc = (sum U / n) x 100%. Diagnosis time is T_diag = t_stop - t_start. When a baseline manual or single-level workflow is measured with identical start/stop conditions, time reduction is R_t = (1 - T_diag / T_baseline) x 100%.

The separation between CR and E_loc is important: CR measures how strongly the search space is reduced, whereas E_loc measures how often the method reaches one uniquely validated root cause. A high candidate reduction alone is therefore not reported as successful localization if the remaining candidate is not independently validated.

Table 2. *Quantitative results matrix to be populated from reproducible diagnostic runs.*

Case	N0	Ns	Nc	L	T div	T diag
C1 Stuck-at	TBD	TBD	TBD	TBD	TBD	TBD
C2 TDF	TBD	TBD	TBD	TBD	TBD	TBD
C3 X-prop.	TBD	TBD	TBD	TBD	TBD	TBD
C4 Scan	TBD	TBD	TBD	TBD	TBD	TBD
C5 CLK/RST	TBD	TBD	TBD	TBD	TBD	TBD

TBD values must be replaced by measurements from the corresponding Tessent/Visualizer/Verdi diagnostic run before final submission. For TDF, report Delta_tLC with the case description; for X-propagation, report t_X, Delta_tX, L_X, and N_Xobs in the case notes. No numerical result should be estimated from screenshots alone. For statistical reporting, CR and T_diag should be calculated for every run and then summarized by fault class. E_loc should be calculated over all validated cases of the same class. If three timing repetitions are performed per case, the median T_diag should be used to reduce operator-induced timing variation. The same measurement procedure is used for Stuck-at, TDF, and X-

propagation cases. In this way, fault diagnosis is evaluated as a digital measurement and information-processing task.

CONCLUSION

The study evaluates a structural-temporal digital correlation method for DFT/ATPG fault localization. Practical DFT debugging is treated as a digital measurement and information-processing problem, where ATPG results, structural connectivity, X-propagation information, and simulation waveforms are processed as a common set of diagnostic attributes.

The diagnostic sequence consists of fault extraction, structural filtering, temporal correlation, and root-cause evaluation. Structural analysis provides spatial information about source, path, and observability, while waveform analysis provides temporal information about the first divergence and its relation to clock, reset, launch, and capture events. The effect of their correlation is evaluated through candidate-set reduction and root-cause localization.

The measurement protocol in Table 1 and the results matrix in Table 2 define the data required for quantitative validation. Stuck-at cases are characterized by fault polarity, mismatch event, candidate counts and structural depth; TDF cases additionally include launch/capture timing; and X-propagation cases include source, observability, X-onset, persistence and propagation depth. From these measurements, CR, E_loc, T_diag and R_t can be calculated without relying on subjective assessment. These measurements characterize DFT fault localization as a digital measurement and information-processing task based on structural and temporal diagnostic data.

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