Testability of Electronic Circuits

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Translated by Klaus Selke

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Foreword

It is with pleasure that I introduce this book to you, for the importance of testability in future designs cannot be overstressed. Indeed, the most technically elegant design, from a functional viewpoint, is absolutely useless if its funtionality cannot be verified in a high-quality, timely and profitable manner.

Manfred and Gerald, in this translation of their original German language book, have not only covered many of the essential testability guidelines previously published in my books, but have also added valuable information on failure types and causes, logic simulation, and the linking of the design environment to manufacturing, test and repair activities via electronic networks.

This book is an excellent text for both the novice in testability design and the electronic design engineer of any skill or experience level. It is my hope that circuit designers in particular will take the information in this book not only to heart but to their workstations. For it is the designer who must implement the guidelines contained herein if new products are to be brought to market more quickly and manufactured more competitively in an increasingly global marketplace.

Testing electronic circuits in the face of ever increasing complexity is becoming more and more difficult. The only viable solution to this expensive problem is the implementation of as many as possible of the techniques described in this book. For without including the three basic testability attributes — partitioning, control and visibility — we may find that we have been so clever in designing new products that we can never verify their performance to a quality level that will allow us profitably to ship them to customers.

Jon Turino
Campbell, CA

List of Abbreviations

A/D	Analog/Digital
ADC	Analog/Digital Converter
ALU	Arithmetic Logic Unit
ANSI	American National Standards Institute
ARINC	Aeronautical Radio Inc.
ASCII	American Standard Code for Information Interchange
ASIC	Application Specific Integrated Circuit
ATE	Automatic Test Equipment
ATLAS	Abbreviated Test Language for All Systems
ATPG	Automatic Test Program Generator
BILBO	Built-In Logic Block Observation
BIT	Built-In Test
BITE	Built-In Test Equipment
BSC	Binary Synchronous Communication
C	Capacity
CAD	Computer-Aided Design
CADIF	CAD Independent Format
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CAP	Computer-Aided Planning
CAQ	Computer-Aided Quality Assurance
CAR	Computer-Aided Repair
CAT	Computer-Aided Testing
CATV	Common Antenna Television, Cable TV
CAX	All Computer-Aided Applications
CCITT	Comité Consultatif International de Télégraphie et Téléphonie
CEPT	Committee of European Post and Telecommunications
CIM	Computer-Integrated Manufacturing

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CMOS	Metal Oxide Semiconductor (Complementary)
CPU	Central Processing Unit
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
D/A	Digital/Analog
DAC	Digital/Analog Converter
DFT	Design For Testability
DIL	Dual-In-Line
DIN	Deutsche Industrie-Norm
DIS	Draft International Standard
EBCDIC	Expanded Binary Coded Decimal Interchange Code
ECL	Emitter Coupled Logic
EDIF	Electronic Design Interchange Format
EGC	Equivalent Gate Count
EPBX	Electronic Private Branch Exchange
ESPRIT	European Strategic Programme for Research and Development in Information Technology
FET	Field-Effect Transistor
FF	Flip-Flop
FOF	Factory of the Future
FTAM	File Transfer, Access and Management
GKS	Graphic Kernal System
HDLC	High-level Data Link Control
HI	High
IC	Integrated Circuit
ICS	Inhouse Communication Systems
IEC	International Electrotechnical Commission
IEEE	Institution of Electrical and Electronic Engineers
IGES	Initial Graphics Exchange Specification
ISDN	Integrated Service Digital Network
ISO	International Standardization Organization
L	Inductance
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LFSR	Linear Feedback Shift Register
LIF	Low Insertion Force
LO	Low
LSI	Large Scale Integration
LSIC	Large Scale Integrated Circuit
LSSD	Level-Sensitive Scan Design
LS(TTL)	Low Power Schottky TTL
L(TTL)	Low Power TTL
MAP	Manufacturing Automation Protocol

MATE	Modular Automatic Test Equipment
MIL-STD	Military Standard
MKSA	Metre-Kilogram-Second-Ampère
MMS	Manufacturing Message Service
MODEM	Modulator-Demodulator
MOS	Metal Oxide Semiconductor
MRCA	Multi Role Combat Aircraft (Tornado)
MSI	Medium Scale Integration
MSIC	Medium Scale Integrated Circuit
MTBF	Mean Time Between Failure
MTD	Mean Time to Detect
MTR	Mean Time to Replace
MTTR	Mean Time To Repair
MTT	Mean Time to Test
MTW	Mean Time to Wait
NBS	National Bureau of Standards
NMOS	Metal Oxide Semiconductor (N-Channel)
OEM	Original Equipment Manufacturer
OSI	Open System Interconnection
PABX	Private Automatic Branch Exchange
PAL	Programmable Array Logic
PBX	Private Branch Exchange
PC	Personal Computer
PCB	Printed Circuit Board
PIA	Programmable Input Adapter
PIO	Parallel Input-/Output Port
PMOS	Metal Oxide Semiconductor (P-Channel)
PN	Pseudo-random Noise
PRBS	Pseudo-random Binary Sequencer
PROM	Programmable Read Only Memory
R	Resistor
RAM	Random Access Memory
ROM	Read Only Memory
SA	Signature Analysis
S-A-0	Stuck-At-Zero, Stuck-At-Low
S-A-1	Stuck-At-One, Stuck-At-High
SAR	Signature Analysis Register
SDI	Scan Data Input
SDLC	Synchronous Data Link Control
SET	Standard d'Exchange et de Transfert
SI	Système International d'Unités
SIO	Serial Input-/Output Port
SMD	Surface Mounted Device

SOS	Silicon On Sapphire
SRL	Shift Register Latch
SSI	Small Scale Integration
SSIC	Small Scale Integrated Circuit
STEP	Standard for Exchange of Product Definition Model
S(TTL)	Schottky TTL
T, t	Time
TCP	Transmission Control protocol
TISS	Tester Independent Support System Software
TP	Test Point
TTL	Transistor—Transistor Logic
TURINO	Totally Universal Reset Initialization and Nodal Observation
VHSIC	Very High Speed Integrated Circuits
VLSI	Very Large-Scale Integration
VLSIC	Very Large-Scale Integrated Circuits
WAN	Wide Area Network
X	Undefined Logic State
Z	High Impedance
ZIF	Zero Insertion Force

Contents

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Basics and Development of Electrical Measuring and Testing Techniques

1.1 TESTING — AN INTERACTIVE PROCESS BETWEEN HUMANS AND THEIR ENVIRONMENT

Testing environmental conditions is one of the natural instincts in all higher forms of life, and it is one of the prerequisites for their survival. Man, the highest form of life, is equipped with sense organs which enable him to survive in his natural environment. However, man does not possess the *best* sensors by any means — many other creatures have sensors which far exceed human ones in terms of sensitivity, resolution, bandwidth, robustness, etc.; and the superiority of humans compared to other creatures can hardly be explained by the high quality of their sensors — rather, it is the combination of sensing *and* intelligence which gives them the advantage.

During the last century, as in many other areas of technology, an evolutionary development took place in instrumentation, with instruments emerging in response to a need for simple sensors for the observation and comprehension of electrical phenomena. The methods used were refined to the limits of the physically possible and any extensions of instrumentational ability seemed unlikely in the foreseeable future. Only since the advent of powerful computers have *intelligent* sensors been realized in modern instrumentation.

Intelligent sensors, supported by computers, can carry out further complex processing of data so that it is possible, for example, to increase considerably the overall measurement accuracy by correlating data from several different types of sensor. Correlating data with previously stored results or experiences further asserts the information content of the data (Figures 1.1 and 1.2).

Early sensor technology was limited to passive observation and surveillance of quantities in the environment. Very early on in that process, however, man was not content with observation alone; he wanted to influence his environment actively. He observed that physical and chemical influences stimulate certain characteristics, that

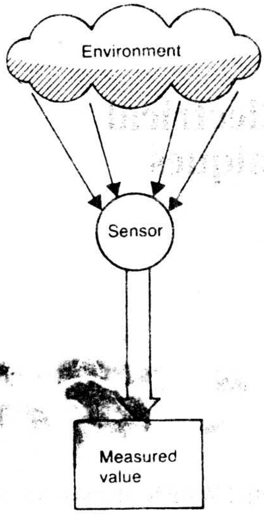

Figure 1.1 Measurement process with one sensor

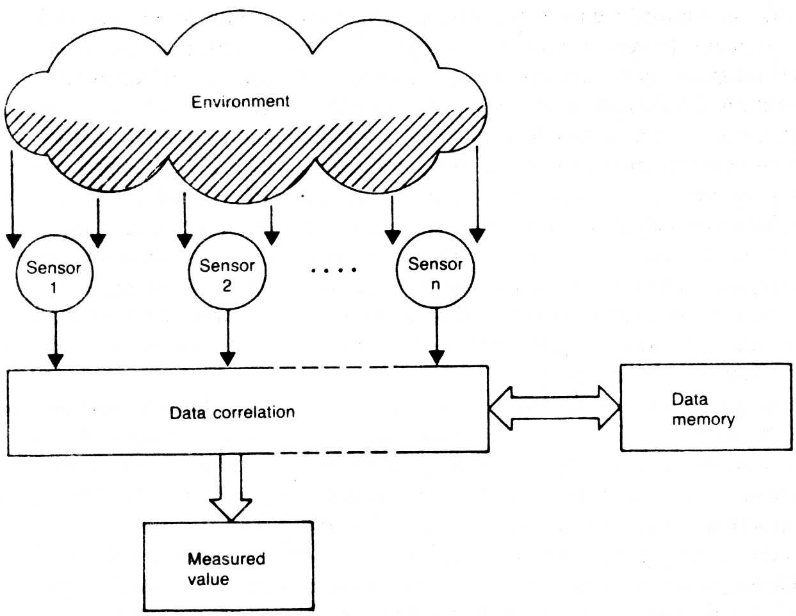

Figure 1.2 Combining measurement values — 'Intelligent Sensor'

these characteristics could be changed reproducibly, and that they allowed man influence over the nature of his environment.

Placed in its historical context, this procedure represented a revolutionary development. It was an achievement of human intelligence because it encompasses such capabilities as awareness of information (sensory perception), storage of information (memory) and drawing of conclusions from this information (inference) (Figure 1.3).

The discussion so far has been restricted to the natural environment of humans. During his development, man began to modify his surroundings imaginatively — he assumed the role of a creator, and was eventually able to transform natural materials by a range of creative abilities available to him and according to his needs and desires. However, it also became necessary to test these transformed materials, and establish their suitability for the task. The knowledge obtained allowed man to influence their characteristics directly for the first time.

To summarize, we can state that man is involved in the testing process:

1. As observer (sensory component).
2. As modifier (stimulus component).
3. As designer (creative component).

Most test procedures involve man in all three activities. Obviously, there is a strong interaction between the effects of all three functions. Such interaction can happen almost

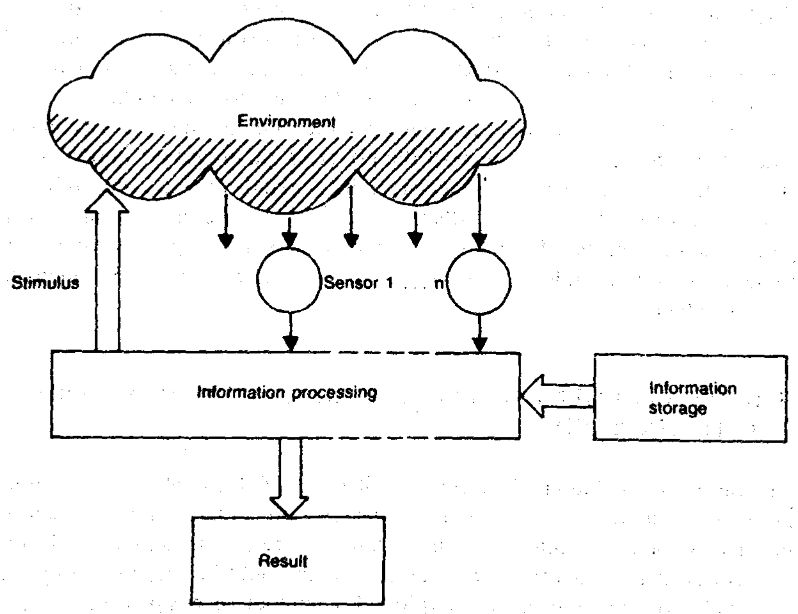

Figure 1.3 Combination of measurement and stimulation signals

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