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ESTIMATE OF MEASUREMENT UNCERTAINTY USING ANALOG SWITCHES IN ELECTRONIC TEST

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Abstract – An analog switch is a component, which can be used in testing analog and mixed-signal units. Analog switches offer the potential to sense nodes on printed board assemblies without physical contact. Generators and analyzers are connected to edge connectors on printed board assemblies and routed via analog switches to the appropriate nodes that are to be measured. The concept of using analog switches in an analog test is introduced in this paper. Measurements of on-resistance dependence on input voltage, supply voltage and temperature are presented. Simulations are presented which show that the use of analog switches, in some cases, increases the uncertainty of measurement. How this can be treated in a manufacturing test is discussed in this paper.

Keywords: uncertainty, analog switch, electronic test

1. INTRODUCTION

Testing analog or mixed-signal units [1] in modern integrated circuits, IC, or printed board assemblies, (PBA) is a challenge due to high packaging density and no available test points. Testing analog or mixed signal units on a system level, e.g. equipped shelves or systems, is an extension of the problem above. The number of methods that can be applied to testing analog or mixed-signal PBAs that have no test points are limited. Functional testing, where stimuli are connected to the inputs of a PBA and where an analyzer is connected to the outputs, is one possible method but the technique is costly due to the amount of work required to achieve high fault coverage. Difficult fault location is also one drawback of functional testing. Complements to using analog switches are, among others, non-contact techniques, such as EMC-signatures [2], the thermograph [3] and the X-ray [4]. The use of analog switches offers the potential to measure analog components and units on ICs and PBAs. By using analog switches, an analog test bus can be designed within an IC or a PBA. There are also standardized components that contain an analog test bus, i.e. the IEEE Std. 1149.4 ("analog boundary scan") [5-10] has been implemented in these circuits. The 1149.4 is an extension of the well-known Standard IEEE 1149.1 [11] ("digital boundary scan"). If an analog test bus is implemented in an IC or a PBA, a generator can be connected to appropriate nodes on the IC or PBA and an analyzer can be connected to other nodes. This technique enables testing at arbitrary nodes. One drawback of using analog switches is the on-resistance (R_{on}), which can affect the uncertainty of measurement in a significant way. Calculations of uncertainty of measurement are essential in both design verification and manufacturing testing as these calculations, to a great extent, determine the classification parameters, i.e. accepted or rejected, based on distances in n-dimensional parameter space. Introduced errors are not deterministic and must be treated in a statistical way, i.e. the primitives are described as probability density functions and functions of stochastic variables (S.V.). Roughly, it can be said that in design verification the purpose is to verify that the design functions properly if the parameters, e.g. R_{on}, are within specification but in a manufacturing test the purpose of the test is to give an fault indication if the parameters are out of specification. The test program in a manufacturing test should detect all modelled errors. This principle is schematically shown in Fig. 1.

Fig. 1. Schematic illustration of the purpose of design validation and manufacturing test. If $a \le x \le b$, X is acceptable otherwise faulty.

One other application in which analog switches can be of value is maintenance when a system is up and running. Analog switches can be used to monitor certain nodes in a system and give an alarm when a certain level is out of the acceptable range. Many nodes in a system can be monitored if each node is connected to an analog bus by analog switches and each node is enabled in an asynchronous or synchronous way. Even in this application, the performance of the analog switches, e.g. R_{on}, has to be taken into consideration when the uncertainty in measurement is calculated. The purpose of this project is to investigate how the use of analog switches in an analog and mixed signal test can influence uncertainty in measurement, especially in a manufacturing test.

2. ELECTRONIC TEST

In an analog test and test of mixed-signal units the imperfections of the interface are vital especially if the interface circuits are placed on the PBA or within the IC. Fig. 2 gives a conceptual illustration of a test system for analog and mixed-signal systems. If the PBA has test points, the interfaces are part of the test system and can be calibrated as a part of the test system. If the interface is placed on the PBA and the situation is design verification, the imperfections of the interface can be characterized and compensated for. In the event that the interface is placed on the PBA and the situation is a manufacturing test, the imperfections of the interface are more difficult to handle and most often have to be dealt with in a statistical way as is shown in this paper.

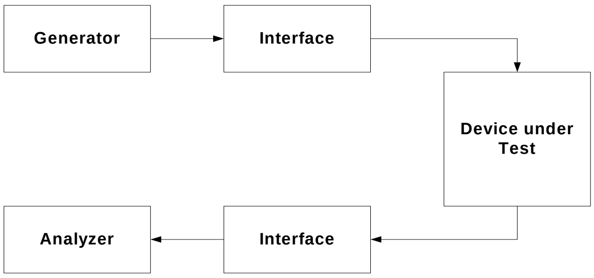

Fig. 2. Schematic of Test System for Analog and Mixed-Signal Systems. The interface part can be either apprehended as a part of the test system or as part of the test object, depending on the situation

If we want to sense a node on a PBA, an analog switch is an alternative that enables a generator or an analyser to be connected to the node. An analog bus can be designed on the PBA to be tested and analysers and generators can be connected to this analog bus. An analog switch is schematically shown in Fig. 3. One possible implementation of an anlog switch is to connect an NMOS- and an PMOS transistor in parallel. A control signal is used to turn the switch on and off.

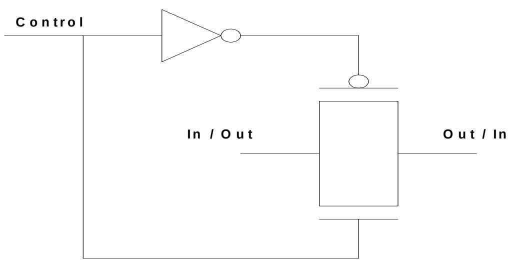

Fig. 3. Schematic of an analog switch. One drawback of using analog switches in testing is that R_{on} depends on temperature, input voltage and supply voltage

Fig. 4 shows an IC which has implemented IEEE Std. 1149.4. In addition to ordinary functionality, this IC has extra functionality for testing an analog and mixed signal circuit. The main extra parts of this extra functionality are a state machine, a test interface circuit (TBIC), analog boundary modules (ABM) and an analog bus. The implementation of 1149.4 enables the potential to connect a generator to one analog test port, e.g. AT1, and an analyzer to another analog test port, e.g. AT2. The analog I/O pins, e.g. AP 1 and AP 2, can be connected to the analog pins we want to sense. This procedure makes it possible to sense any node on a PBA via an 1149.4 compliant circuit. The philosophy of using anlog switches to sense nodes can also be extended to internal nodes on an IC or on a system or sub-system level. One important part of this philosophy is design for test (DFT) which emphasises test as an activity that has to be planned for from the beginning of the design phase and can hardly be included when the design phase is ended.

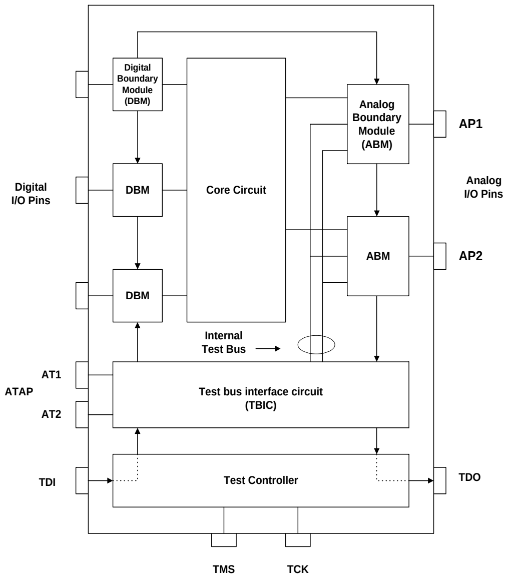

Fig. 4. 1149.4 Compliant Circuit

Duzevik [9] has presented preliminary results of passive component measurement methods using an IEEE 1149.4 compliant device, i.e. the SCASTA400 [12]. In this reference, both the potential and the limitations of 1149.4 compliant circuits are discussed.

3. EXPERIMENT

One problem in using analog switches in testing is that R_{on} depends on, among other factors, applied voltage, supply voltage, and temperature. This is illustrated in Figures 5, 6 and 7 below. An IC has been used in the experiments presented below, i.e. 74HCT4066 [13]. In these experiments, the voltage is measured between V_{in} and V_{out} and the current is measured from V_{out} to ground. A load, i.e. R_L = 1000 Ω, is used. As R_{on} ,in some cases, affects the uncertainty in measurement, the characterisation of R_{on} is of vital interest. Fig. 5 shows the R_{on} dependence of the input voltage. The result of this change in R_{on} caused by altering the input signal results in a non-linear behaviour of the analog switch, thus resulting in sine wave distortion. Result from simulation of this distortion was presented by Persson [14].

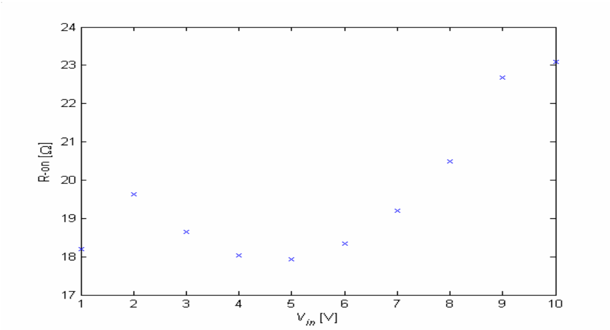

Fig. 5 R_{on} as a function of V_{in}. V_{cc} = 10 V, T ≈ 20 °C

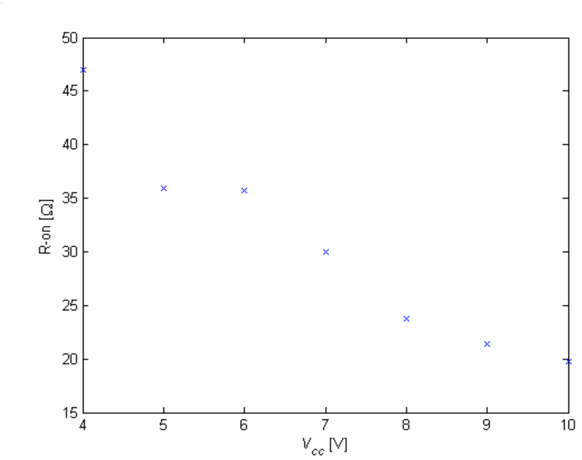

Fig. 6 R_{on} as a function of V_{cc}. Vin = 2 V, T ≈ 20 °C.

Fig. 6 shows how R_{on} depends on the supply voltage, a lower supply voltage results in a lower R_{on}. This may cause minor problems in the manufacturing test if the supply voltage varies moderately among different components in a batch of components. As can be seen in Fig. 6, increasing V_{cc} voltage decreases R_{on}. This is opposite to what is preferable, i.e. a low V_{cc} and a low R_{on}.

Fig. 7 shows how R_{on} depends on temperature. The drawback of this change in R_{on} due to temperature, depends on the application, e.g. in an automotive application it can affect the uncertainty in measurement in a significant way, but if the temperature is controlled the problem is minor. The climate chamber Excal [15] was used in this experiment.

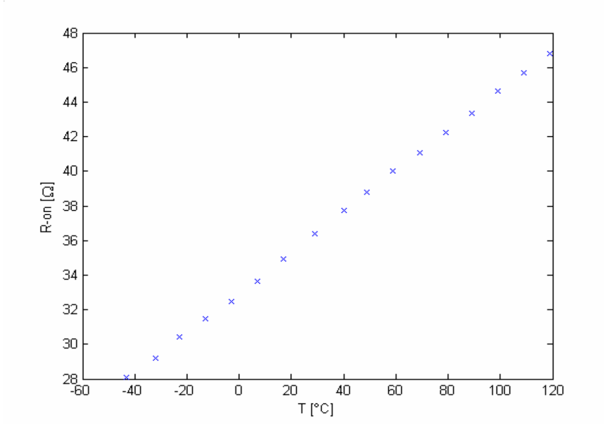

Fig. 7 R_{on} as a function of temperature. V_{cc} = 5 V, V_{in} = 4 V

4. UNCERTAINTY IN MEASUREMENT

The problem of testing parameters of electronic components is schematically illustrated in Fig. 8. If a certain parameter, e.g. R_{on} , is in between a and b, the component is classified as acceptable otherwise classified as faulty. The problem in manufacturing test is to determine a and b if we want a certain confidence that the parameter of interest is within a and b. This is a trivial problem if we can take a component and locate it in a traceable calibrated instrument. In manufacturing test this problem is more difficult. The component is mounted on a PBA and therefore difficult to verify. A solution to this problem, as mentioned above, is to connect the generator through one analog switch to the generator node, and the analyser to the analyzer node through another analog switch, see Fig. 2. The analog switches are placed within the PBA so it is seldom possible to calibrate the switches individually when manufacturing PBAs.

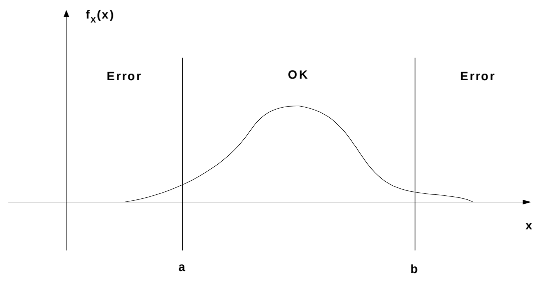

Fig. 8. p.d.f. of a S.V. describing a parameter, e.g. R_{on}

It is not possible to set strict proper pass/fail limits in a manufacturing test or design validation, in the sense that no acceptable components will be less than a or greater than b, see Fig. 9. Even if R_{on} in the analog switches is known in advance, i.e. deterministic knowledge, the analyzer, i.e. a voltmeter has an uncertainty in measurement due to non-ideal calibration. In order to be able to set stringent pass/fail borders, i.e. no component classified as acceptable will be faulty and no component classified as faulty will be acceptable, a rectangular p.d.f. is needed in the traceable calibration process for the test instrument. This is hard to achieve, even if state of the art calibration is used. Their calibration certificates describe the measurement uncertainty of the generator and analyser. S.V.s are suitable for treating the problems discussed above. In some applications, e.g. when there is a need to run a quick test or a diagnostic to see if a voltage divider is working properly this is not a problem, but in making precise measurements the above mentioned problem is crucial, e.g. a precision resistor mounted on a PBA is to be validated. The concepts of “zero defectives”, “min” or ”max” that relate to engineering specification are questionable in a strict way. Consequently, it is reasonable to state that Pr ($W \leq \alpha$) < Δ is denoted zero defectives, W being a S.V. that describes the variable of interest in classifying items as acceptable or faulty.

Assume that a resistor is to be measured through an analog switch or a number of switches, e.g. IEEE 1149.4 compliant circuits, the analog switch can be modelled as a stochastic variable X and the resistance to be measured as another S.V. Y. One terminal of the resistor is connected to the analog switch and the other one is connected to ground. A voltage is applied to the analog switch and the resistor voltage is used as a classification parameter. The measured voltage is a voltage division that corresponds to the stochastic variable Z:

$$Z = X / (X + Y) \qquad (1)$$

Assume an acceptance interval of $49 \leq R \leq 51$, R is to be unit distributed, i.e. U(49,51), and R_{on} is known to be 50 Ω , then all resistors will be correctly classified. However, if R_{on}, is changed according to applied voltage, temperature, differences within one component or within one batch of components, see Section 3., the number of resistors classified as faulty, even if they are acceptable, is shown in Table 1.

TABLE 1. Fault dependence on R and R_{on}

R_{on} [Ω]	Fault [%] R is U[49 ; 51]	Fault [%] R is N[50 ; 0.5^2]
50	0	5
U[49.5 ; 50.5]	12	8
N[50 ; 0.25^2]	9	7

Results achieved if R is gamma-distributed are shown in Table 2.

TABLE 2. Fault dependence on R and R_{on}

R-on [Ω]	Fault [%] R is Γ[10000; 0.005]
50	5
Γ[20000; 0.0025]	11

Useful relations [16] in calculating or simulating Z are:

$$f_{\frac{X}{X+Y}}(t) = \left(\frac{1}{1-t}\right)^2 f_{\frac{X}{Y}}\left(\frac{t}{1-t}\right), 0<t<1 \qquad (2)$$

and also if

X and Y are independent, X is $\Gamma(a_1,b)$ and Y is $\Gamma(a_2,b)$ then Z = X / (X + Y) is Beta(a_1, a_2).

Tables 1 and 2 clearly show that the uncertainty of measurement can be affected by the distribution of R_{on}. As a consequence of this, the risk of classifying components as faulty if they are acceptable or acceptable if they are faulty depends on the way R_{on} is estimated. The distributions used in this paper are defined in Appendix. The results presented in Tables 1 and 2 are based mainly on simulations made in Matlab.

5. CONCLUSION

The measurements and simulations presented in this paper illustrate the increase in the uncertainty of measurement when using analog switches as a tool for testing analog and mixed-signal PBAs. There are few alternatives to analog switches for testing discrete components in PBAs, consequently the increase in the uncertainty of measurement has to be dealt with. In design verification, great effort may be spent on one single PBA, but in manufacturing testing, statistical process control has to be used. Improved process control when manufacturing analog switches, i.e. the control of the variation of R_{on} in a batch of components, will decrease the drawbacks of using analog switches in testing.

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Appendix

Uniform , $U(a,b)$

$$f(x) = \frac{1}{b-a} \; ; \; a < x < b$$

Normal, $N(\mu,\sigma^2)$

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \; ; -\infty < x < \infty; -\infty < \mu < \infty; \sigma > 0$$

Gamma , $\Gamma(a,b)$;

$$f(x) = \frac{1}{b^a \Gamma(a)} x^{a-1} e^{-\frac{x}{b}} \; ; \; x > 0; a > 0; b > 0$$

Beta, $Beta(r,s)$

$$f(r,s) = \frac{1}{B(r,s)} x^{r-1}(1-x)^{s-1} \; ; \; 0 \le x \le 1; r > 0; s > 0$$

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