Measurements in 1149.4 environments – correcting the infrastructure switches influence

Manuel C. Felgueiras[1], Gustavo R. Alves[1], J. M. Martins Ferreira[2]
{mcf, gca}@isep.ipp.pt, jmf@fe.up.pt
1 ISEP / LABORIS – Rua Dr. António B. de Almeida – 4200-072 Porto – PORTUGAL
2 FEUP / DEEC – Rua Dr. Roberto Frias – 4200-465 Porto - PORTUGAL

Abstract

Measuring the values of discrete components frequently takes place during the test or debug phase of Printed Circuit Boards (PCB). This operation requires tools that are based on some access type. The shrinking geometries constrain the straightforward use of tools based on physical access. One of the aims of the IEEE1149.4 Std. is to facilitate those on-board measurements. This infrastructure relies on electronic access that includes high quality analog buses and a set of electronic switches, which enable to completely isolate a component under characterization, e.g. by injecting a known current and measuring the voltage across it. During this process, the infrastructure switches have a negative impact in the measurement accuracy. This paper analyses the measurement of one resistor in two situations: connected between a pin and ground and between two pins. The infrastructure switches that affect the measurement quality are identified and the upper limit of its systematic error is characterized. When the systematic error is completely defined then it is possible to remove its negative effect from the final result.

1. Introduction

In many PCB´s, discrete components are mainly used for coupling different circuit stages and for device configuration. The IEEE1149.4 [1] test infrastructure was presented as a formal extension of the IEEE1149.1 [2] Std. for the Mixed-Signals (MS) area. Its scope includes:

- interconnect test
- parametric test (characterization of discrete components)
- internal test

The IEEE1149.4 test infrastructure includes high quality internal analog buses that can be used as embedded analog probes, when the PROBE mandatory instruction is selected. The standard stipulates a minimal set of mandatory requirements while also allowing its reuse for many others purposes. The infrastructure reuse are suggested to:

- detect deviations to the nominal performance [3]
- perform RF measurements [4]
- on-line monitoring and reconfiguring functions in safety critical applications [5]
- perform analog diagnosis through the quiescent nodal analog voltage [6]
- support the testing of ADCs and DACs [7]
- support debug operations in MS circuits [8,9]
- test specific parameters of digitals circuits (e.g. V_{IH}) [10]

The market acceptance of this test infrastructure has been slow and to promote it, several actions have taken place: (a) one compliant Integrated Circuit (IC) has been produced [11]; (b) analog extension to BSDL has been proposed to support automatic test generation [12]; (c) a check integrity procedure has been proposed [13]; (d) its use for monitoring internal analog/digital nodes [9]. It is clear today the benefits due to the use of analog buses to support measurements, even in digital circuits, as presented and patented by INTEL [14]. The tradeoffs associated to the costs and the benefits are encouraging the use of this test infrastructure [15,16]. The analog infrastructure bus characterisation and some experimental results have been presented [17,18].

The present work analyses the individual errors introduced by the 1149.4 switches during the measurement process of one resistor. We describe a methodology to remove the effect introduced by each involved switch, whenever possible. We use the 1149.4 compatible IC SCANSTA400 [19] to verify and validate our analysis. This work intends to provide a simple formula to correct the measurement process errors caused by non-ideal switches. This formula is especially useful for those people that use the analog bus to perform measurements through electronic access.

2. Determining the value of one resistor placed between an ABM and GND

The methodology to calculate the value of a resistor, via the 1149.4 infrastructure, consists on: (1) injecting a known current value in the resistor, via AB1, and (2) measuring the voltage across the resistor, via AB2, as presented in Figure 1.

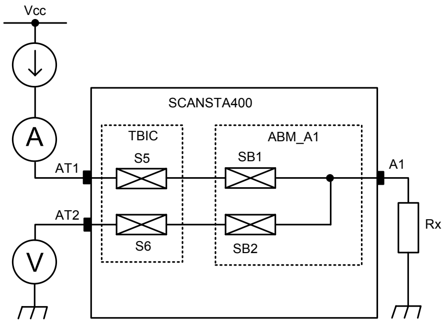

Figure 1 – Determining the value of one resistor placed between an ABM and GND.

The source current is recommended to provide a stable current value and also to prevent excessive current values that may damage test infrastructure during the measurement operation. The initial value for R_X is R_1, and its value is calculated by:

$$R_1 = V_1 / I_1 \qquad [2.1]$$

where V_1 and I_1 correspond to the initial measured values of the voltage and current across R_x, respectively. The resistor calculated value is affected by several error sources:

- ε_V – associated to the voltmeter accuracy
- ε_A – associated to the ammeter accuracy
- ε_{M1} – associated to the switches resistance R_{SB2} and R_{S6} ($R_{SB2} + R_{S6} > 0\ \Omega$)
- ε_{M2} – associated to the voltmeter resistance ($R_V \neq \infty\Omega$)

The total relative error in the calculation process of R_x is given by:

$$\varepsilon_{RX} = \varepsilon_V + \varepsilon_A + |\varepsilon_{M1}| + |\varepsilon_{M2}| \qquad [2.2]$$

ε_V is the relative error due to the voltmeter limited accuracy and its value is usually indicated in the respective instrument manual. ε_A is the similar relative error for the ammeter. ε_{M1} corresponds to the error introduced by the measurement methodology, and is due to the influence of the switch resistances SB2 (R_{SB2}) and S6 (R_{S6}). The voltage measured by the voltmeter is lower than the actual voltage across Rx, as it includes the voltage drop at R_{SB2} and R_{S6}. The reduction of the voltage measured by the voltmeter is given by:

$$\Delta V = -\,(R_{SB2} + R_{S6}) \,.\, I_V \qquad [2.3]$$

and the associated error is:

$$\varepsilon_{M1} = \Delta V / V = -\,(R_{SB2} + R_{S6}) / R_V \qquad [2.4]$$

where R_V is the voltmeter internal resistance. The minus signal means that the voltage measured by the voltmeter is less than the expected value and hence the calculated R_X will be lower than the correct value. To remove this error, a new value should be calculated as follows:

$$V_2 = V_1\,[\,1 + (R_{SB2} + R_{S6}) / R_V)\,] \qquad [2.5]$$

The IEEE1149.4 Std. defines that value of RSW2 (equal to RSB2 plus RS6, i.e. RSW2 = RSB2 + RS6) should be lower than 10 kΩ1 (a similar definition is made for RSW1). We now have two possibilities: (1) if the exact value of RSB2 + RS6 is known, we calculate V2 and hence εM1 = 0; (2) if only the upper limit of RSB2 + RS6 is known, a new voltage value V2, equal to V1, will be used in the following calculations. In this last case, εM1 should be calculated through formula [2.4]. In both we consider a new current value I2, equal to I1, to be used in the following calculations. εM2 is the other method error and is due to the voltmeter internal resistance. The V2 / I2 relation does not correspond to the desirable calculated resistance but to a parallel association between R2 and RV, i.e.:

$$V_2 / I_2 = R_2 = (R_3 \,.\, R_V) / (R_3 + R_V) \qquad [2.6]$$

To remove this error, a new resistance value R_3 must be calculated as follows:

$$R_3 = R_2 / [\,1 - (R_2 / R_V)\,] \qquad [2.7]$$

where:

$$\varepsilon_{M2} = -\,(R_2 / R_V) \qquad [2.8]$$

[1] IEEE1149.4Std., 9.4.1.b

In order to better understand the previous operations, a chart with the implicit algorithm is presented in Figure 2.

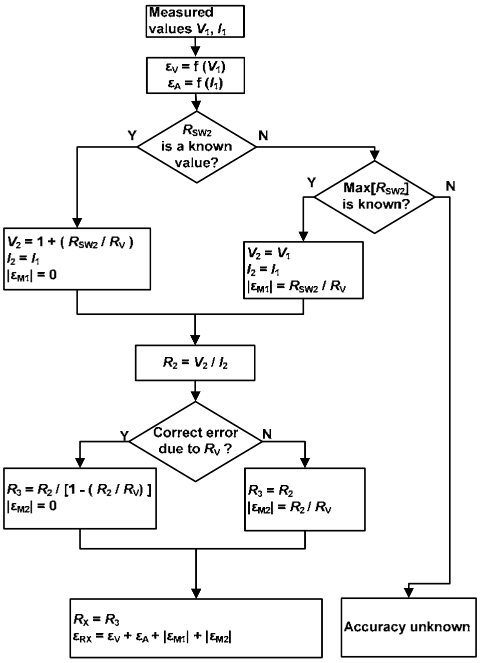

Figure 2 – Rx algorithm calculating the value of a resistor placed between an ABM and GND.

The chart includes all possible decisions in the R_X calculation process, allowing the user to evaluate the impact of a given error source (e.g. the non-zero R_{SB2} ohmic value) in the final result. Notice that not every switch included in the measurement path (e.g. R_{SB1}) affects the R_X calculation process.

3. Determining the value of one resistor placed between two ABMs

The measurement of one resistor placed between two ABMs is similar to the case analysed in the previous section, as we can see in the Figure 3.

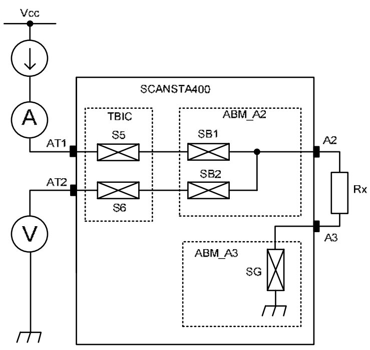

Figure 3 - Determining the value of one resistor placed between two ABMs.

The difference is that we now have a new error source due the presence of R_{SG}. The initial value for the calculated R_X is again given by:

$$R_1 = V_1 / I_1 \qquad [3.1]$$

However, the total relative error of R_x is now:

$$\varepsilon_{RX} = \varepsilon_V + \varepsilon_A + |\varepsilon_{M1}| + |\varepsilon_{M2}| + |\varepsilon_{M3}| \qquad [3.2]$$

Errors ε_{M1} and ε_{M2} were explained in the previous section. ε_{M3} is a new method error associated to the presence of R_{SG}. The calculus of R_X follows the same steps as explained in the previous section until a value for R_3 is obtained. However this value does not correspond to the real resistance between the two pins, but rather to a series formed by R_4 and R_{SG}, i.e.:

$$R_3 = R_4 + R_{SG} \qquad [3.3]$$

The error value ε_{M3} is given by:

$$\varepsilon_{M3} = R_{SG} / R_3 \qquad [3.4]$$

To remove this error, R4 must be calculated as follows:

$$R_4 = R_3 - R_{SG} \qquad [3.5]$$

which, by its turn, requires characterizing the internal resistor R_{SG}. This may be done with an additional test, as presented in Figure 4.

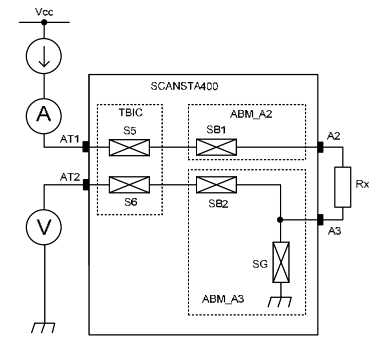

Figure 4 – Determining the resistance value of the R_{SG} switch.

To determine the ohmic value of R_{SG} the rules explained in the previous section should be applied. Notice that in the configuration presented in Figure 4, R_X is in series with R_{S5} and R_{SB1}, which do not affect the measurement process, as the resistor under characterization is now R_{SG}. In order to better understand the previous operations a new chart with the implicit algorithm is presented in figure 5.

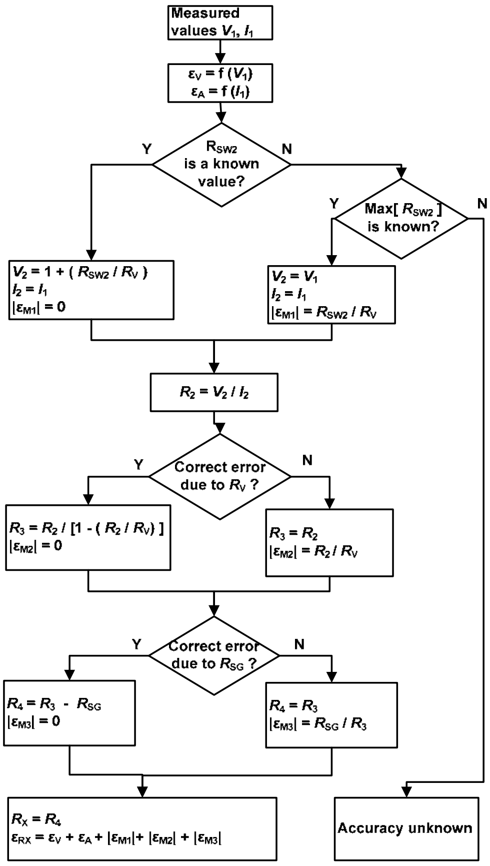

Figure 5 - *R*x algorithm calculating the value of a resistor placed between two ABMs.

4. The case study

Our analysis was validated with the IC SCANSTA400, an 1149.4 compatible IC. The data-sheet of this IC contains only the basic information and the values for R_{SW1} and R_{SW2} are not supplied. Thus we have made some tests to determine them. The obtained results are presented in Table 1.

Table 1 - R_{SW1}/R_{SW2} resistor values for the IC SCANSTA400.

Pin name	Current value (mA)	Voltage value (V)	$R_{SW1/2}$ location	$R_{SW1/2}$ value (kΩ)
A1	0,436	0,3955	R_{SW1_A1}	0,907
A1	0,435	0,3957	R_{SW2_A1}	0,909
A2	0,435	0,3978	R_{SW1_A2}	0,914
A2	0,435	0,3957	R_{SW2_A2}	0,909
A3	0,435	0,3980	R_{SW2_A3}	0,915

The schematic o the used current source is presented in Figure 6, for illustrative purposes.

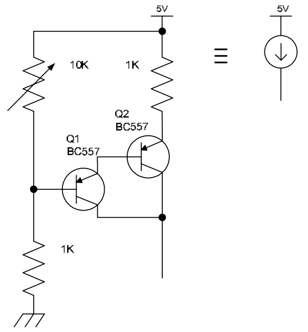

Figure 6 - Current source used during the measurement operations.

For measuring one resistor placed between an ABM and GND we used the circuit showed in Figure 1. To control the IC TAP (Test Access Port) we used an in house PC application, named JTAGer [20], which can control two TAPs. The program is presented in Annex 1. The voltage and current values read are:

V_1= 2,176 V [4.1]

I_1= 0,458 mA [4.2]

The initial value for R_X is:

R_1 = 2,176 / 0,458 . 10 $^{-3}$ = 4,75 kΩ [4.3]

The relative error ε_{RX} is calculated as follows:

ε_V= 0,05%RDG + 3 DIG = 0,0019 or 0,19% [4.4]

ε_A= 0,05%RDG + 3 DIG = 0,0071 or 0,71% [4.5]

$|\varepsilon_{M1}|$= $\Delta V/V$ = (R_{SB2} + R_{S6})/R_V = R_{SW2_A2}/ R_V = 907 / 10.10^6 = 0,01% [4.6]

$|\varepsilon_{M2}|$ = R_M/R_V = 4, 75 .10^3 / 10 . 10^6 = 0,0005 or 0,05% [4.7]

ε_{RX} = ε_V + ε_A + $|\varepsilon_{M1}|$ + $|\varepsilon_{M2}|$ = 0,19 + 0,71 + 0,01 + 0,05 = 0,96 % [4.8]

In this case it is not possible to remove errors ε_{M1} and ε_{M2} because they are much less than the sum given by $\varepsilon_V + \varepsilon_A$, thus the correcting operations have no effect. In this case, using a voltmeter and an ammeter with higher accuracy (i.e. equal to or less than 0,1%) would cause the errors associated to the method (ε_{M1} and ε_{M2}) to have an higher impact in the calculation of R_X. The resulting R_X is:

$$R_X = R_1 = 4{,}75\ k\Omega \quad [4.9]$$

The overall accuracy in this calculation method is less than 1%. The value of R_X measured with a high accuracy instrument is:

$$R_{XH} = 4\ 757{,}0\ \Omega \quad [4.10]$$

so a coherent value has been obtained. For measuring one resistor placed between two ABMs we used the circuit illustrated in Figure 3. The correspondent JTAGer program is presented in the Annex 2. The voltage and current values read are:

$$V_1 = 2{,}412\ V \quad [4.11]$$

$$I_1 = 0{,}448\ mA \quad [4.12]$$

To characterize R_{SG} we use the circuit illustrated in Figure 4. The obtained results are:

$$V_{SG} = 0{,}2732\ V \quad [4.13]$$

$$I_{SG} = 0{,}447\ mA \quad [4.14]$$

$$R_1 = 2{,}412 / 0{,}448\ .\ 10^{-3} = 5{,}38\ k\Omega \quad [4.15]$$

The relative error ε_{RX} is :

$$\varepsilon_V = 0{,}05\%RDG + 3\ DIG = 0{,}0017 \text{ or } 0{,}17\% \quad [4.16]$$

$$\varepsilon_A = 0{,}05\%RDG + 3\ DIG = 0{,}0072 \text{ or } 0{,}72\% \quad [4.17]$$

$$|\varepsilon_{M1}| = \Delta V/V = (R_{SB2} + R_{S6})/R_V = R_{SW2\_A2}/ R_V = 909 / 10.10^6 = 0{,}01\% \quad [4.18]$$

$$|\varepsilon_{M2}| = R_M/R_V = 5{,}38\ .10^3 / 10\ .\ 10^6 = 0{,}0005 \text{ or } 0{,}05\% \quad [4.19]$$

The calculated value for R_{SG} is:

$$R_{SG} = 0{,}2732 / 0{,}447\ .\ 10^3 = 611\ \Omega \quad [4.20]$$

Notice that in the calculation process of R_{SG} the associated ε_{M1} and ε_{M2} errors may be disregarded. Returning to the calculation of R_X, the value for ε_{M3} is obtained through:

$$\varepsilon_{M3} = R_{SG} / R_M = 611 / 5{,}38\ .\ 10^3 = 0{,}114 \text{ or } 11{,}4\% \quad [4.21]$$

This error source is unacceptable and must be removed.

$$R_4 = R_{M3} - R_{SG} = 5{,}38\ .\ 10^3 - 0{,}611\ .\ 10^3 = 4{,}77\ k\Omega \quad 4.22]$$

The total error and the final value for R_X are, respectively.

$$\varepsilon_{RX} = \varepsilon_V + \varepsilon_A + |\varepsilon_{M1}| + |\varepsilon_{M2}| + |\varepsilon_{M3}| = $$
$$= 0{,}17 + 0{,}72 + 0{,}01 + 0{,}05 + 0 = 0{,}95\ \%$$

$$R_X = R_4 = 4{,}77\ k\ \Omega \quad [4.24]$$

The obtained result is also coherent. Notice that the ε_{M3} error source has been removed. To achieve better results it is imperative to use T&M instruments with better accuracy.

5. Conclusion

The measurement in discrete components using electronic access mechanisms is an usual task in present integrated systems. In this work we proposed a methodology to analyse the errors introduced by the 1149.4 infrastructure in order to evaluate when its impact in the measurement quality is acceptable or be removed. Although the presented analysis has been conducted on an IEEE1149.4 compliant device, the calculation method may be applied to other analog buses. The impact of each switch has also been characterized, which may help analog designers to better understand which particular switch type to use in a particular location.

Annex 1

```
;Determining the value one resistor placed
:ABM_A1 - GND
```

```
;IC: SCANSTA400-National
;Author: M.Felgueiras
;Test conditions:
;     Mode=0
;     C0=0
;     C1=0
;     CE=1
;     CE1=0
;
start:              //
seltap0;            //
serflg0;            //
rst;                //
                    //
A:                  //
                    //
state irshift;      //
ld cnt,20d;         //
nshfcp 1FFFEh,80000h,C0000h; //
jerr ERROR;         //
tms1;               // IR<- SAMPLE/PRELOAD
                    //
state drshift;      //
ld cnt,48d;         //
nshf 00000300C000h; //
jerr ERROR;         //
tms1;               // BSR <- DATA
                    //
state irshift;      //
ld cnt,20d;         //
nshfcp 00000h,80000h,C0000h;
jerr ERROR;        //
tms1;              // IR <- EXTEST:Read V1, I1
                   //
jmp A;             //
                   //
ERROR:             //
halt;              //
```

Annex 2

```
;Determining the value one resistor placed
:ABM_A1 - GND
;IC: SCANSTA400-National
;Author: M.Felgueiras
;Test conditions:
;     Mode=0
;     C0=0
;     C1=0
;     CE=1
;     CE1=0
;
start:              //
seltap0;            //
serflg0;            //
rst;                //
                    //
state irshift;      //
ld cnt,20d;         //
nshfcp 1FFFEh,80000h,C0000h;
jerr ERROR;         //
tms1;               // IR <- SAMPLE/PRELOAD
                    //
state drshift;      //
ld cnt,48d;         //
nshf 0000030100c0h; //
jerr ERROR;         //
tms1;               // BSR <- DATA
                    //
state irshift;      //
ld cnt,20d;         //
nshfcp 00000h,80000h,C0000h;
jerr ERROR;         //
tms1;              // IR<- EXTEST; Read V1, I1
                    //
                    //
state drshift;      //
ld cnt,48d;         //
nshf 000003050080h; //
jerr ERRO1;         //
tms1;               // Read VSG and ISG
                    //
ERROR1:
halt;               //
```

Acknowledgements

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