Measurements of Passive Components Using of an IEEE 1149.4 Mixed-Signal Test Bus

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Abstract **-** The paper presents results of investigations on the use of a mixed-signal test bus IEEE 1149.4 for measurements of passive RLC elements placed on electronic circuit boards. In the tests integrated circuits the STA400, the first commercial integrated circuits compliant with the IEEE 1149.4, were used. Measurements were carried out using methods proposed in the IEEE 1149.4 standard as well as newly-developed methods oriented at bus testing. The methodology of measurements and the achieved results are also presented.

I. Introduction

The development of production technologies of electronic devices creates substantial problems with their testability. Conventional in circuit and functional testing systems of analog and digital circuits are nowadays becoming less and less usable due to the limited access to nodes of the circuit under test.

One of the proposals aimed at increasing the testability of circuits is the mixed-signal test bus IEEE 1149.4 standard, developed in 1999 [1]. This standard provides access through a two-wire analog bus to integrated circuit terminals and allows to connect the driving signals and to measure their response. This permits testing of connections between the circuits, the measurement of analog circuit characteristics and testing for the presence and value of discrete elements connected to circuit terminals.

The first commercially available integrated circuit equipped with the IEEE 1149.4 bus is the STA400, developed by National Semiconductor and Logic Vision. This circuit, initially available only for research purposes, is presently also available commercially [2] and is recommended for use in the electronic, automobile and aircraft industry as well as in military applications.

II. Description of the STA400

The STA400 integrated circuit (Fig. 1) is an analog multiplexer/demultiplexer with a built-in IEEE 1149.4 test bus.

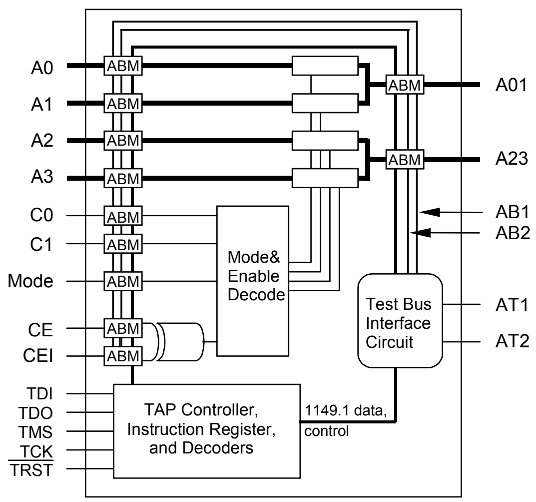

Fig. 1. Block diagram of the STA400

The core of the circuit consists of four analog switches (lines A0-A23) and a decoder responsible for the activation of the appropriate switch. There is an Analog Boundary Module (ABM) between each functional terminal of the circuit and the core. Two on-chip Analog Buses, AB1 and AB2 are connected to two off-chip Analog Buses, AT1 and AT2 through analog switches in the Test Bus Interface Circuit (TBIC). The Analog Bus AT1/AB1 is used primarily as a current drive path and the Analog Bus AT2/AB2 is used primarily as a voltage sense path.
Nine ABM modules (without modules CE and CEI) can be used as virtual measurement probes, by means of which we can stimulate and observe analog signals at circuit terminals via the analog bus AT1, AT2. This property has been used for the measurement of passive RLC elements situated on electronic boards.

III. Resistance measurements

Because of large resistance values of the analog bus switches, nonlinearly dependent upon the applied voltages, recommended by the IEEE 1149.4 standard diagnostic methods require foremost the use of current stimulation.

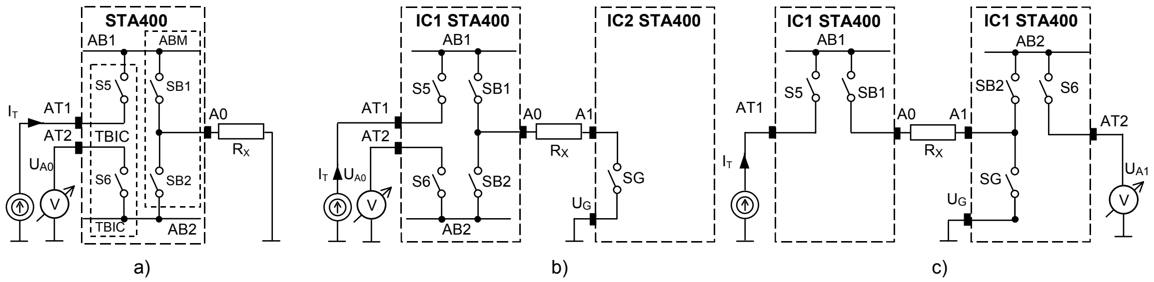

Fig. 2. Resistance measurement of an element using the IEEE 1149.4 bus

In the case when the resistor being measured was connected with one end to ground, measurements were carried out in the configuration shown in Fig. 2a. Resistor R_x was stimulated from a current source through line AT1 via switches S5 of module TBIC and switch SB1 of module ABM. The voltage was measured with a HP 34401A multimeter via bus line AT2 and switches S6 and SB2. The resistance was determined from the relation

$$R_x = U_{A0}/I_T \,. \tag{1}$$

For a resistor placed between ground and terminals of one or two integrated circuits (Fig. 2 b, c), the connection of one end with ground has been accomplished with the use of switch SG in the ABM module. In a similar way as before, the current stimulation was applied through line AT1 of the bus, while the voltages at terminals A0 and A1, to which the resistor was connected, were measured through line AT2. Resistance R_x was determined as

$$R_x = (U_{A0} - U_{A1})/I_T \,. \tag{2}$$

The results obtained in both configurations with a current I_T = 100 µA are shown in Table 1, where R_{nom} is the resistance value measured directly with the HP 34401A multimeter and R_x is the resistance value determined through measurements via the bus.

Table 1. Measurement of resistance with the use of an external current source

	R_{nom}	10,205	100,253	1000,60	10003,2
resistor connected with one end to ground	R_x [Ω]	10,11	100,57	1004,85	10040,7
	δ [%]	-0,93	0,32	0,42	0,37
resistor connected between integrated circuits	R_x [Ω]	15,96	100,62	1008,17	10002,3
	δ [%]	56	5,9	0,76	0,20

As evident, in the second configuration the errors are considerably higher, particularly with resistors of small resistance values. An analysis of this effect has shown that it is caused by internal voltage drops in the integrated circuit, across the resistance of leads of the ABM module to node A1 to which the SG switch of the ABM module is connected. These voltage drops of single millivolts have a very negative effect upon the measurement of resistors with low resistances. An improvement in accuracy by using an additional pin (e.g. A2) for the measurement of voltage in node A1 has been suggested. This solution allowed an improvement of accuracy by one order. The results obtained are shown in Table 2.

Table 2. Measurement of resistance with the use of an additional pin

	R_{nom} [Ω]	10,205	100,253	1000,60
resistor connected between integrated circuits	R_x [Ω]	10,600	100,64	1001,00
	δ [%]	3,9	0,39	0,04

Because of limitations introduced by methods using a current source, a measurement of resistance has been proposed with the use of an additional standard resistor and a voltage source U_H in the ABM module, used to force a logical „1" state.

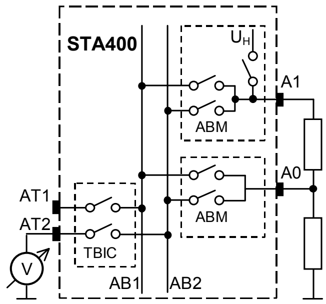

Fig. 3. Measurement of resistance with the use of a voltage source U_H in the ABM module

A diagram of the measurement circuit is presented in Fig.3. The measured resistor R_x is driven from a voltage source U_H through an additional standard resistor R_w. Voltages U_{A0} and U_{A1} are measured through bus lines AT2 ; this allows to determine the current I_x flowing through the resistor R_x

$$I_x = \frac{U_{A1} - U_{A0}}{R_w} \quad . \tag{3}$$

Knowing the current and voltage across R_x we can determine its value from

$$R_x = U_{A0} \frac{R_w}{U_{A1} - U_{A0}} \quad . \tag{4}$$

The results of a verification of the described method for R_w = 1 kΩ are shown in Table 3. As seen, the described method permits to measure the resistance of the R_x element in the range of single ohms to tens of kiloohms, with an error not exceeding 0.5 %. This method does not require the use of a current source, but only one additional resistor. An extension of the range of measured resistances can be achieved through a change of the value of resistor R_w.

Table 3. Measurement of resistance R_x with the use of a voltage source U_H

R_{nom} [Ω]	10,205	100,253	1000,60	10003,2	100030
R_x [Ω]	10,244	100,30	1000,8	9986,9	98506
δ [%]	0,39	0,05	0,02	-0,16	-1,5

Presented methods can be used for the measurement of single resistors. In order to measure multi-element structures, a diagnostic method utilizing Tellegen's theorem [3, 4] is suitable. This method, along with results of a practical verification for 3 and 5 element structures, has been described in [5, 6].

IV. Capacitance measurements

Standard IEEE 1149.4 proposes the measurement of impedance by using a current stimulation and measurement of voltage. These measurements require a precision source of alternating current and a vector voltmeter allowing the measurement of amplitude and phase of voltage. The method described above can be used in laboratory conditions, but in engineering practice other methods using commonly available measuring instruments are more appropriate.

Below we describe two such methods, measuring capacitance only with the use of a variable-frequency generator and a simple alternating voltage meter without the phase measurement facility.

The first method [7] is based on the determination of the 3 dB cut-off frequency of a low-pass filter created by the capacitor under measurement and the resistance R of series-connected switches in modules TBIC and ABM. The cut-off frequency is determined through a change of the generator's frequency and monitoring of the voltage across the capacitor. The capacitance is determined from the relation

$$C_x = \frac{1}{2\pi f_{3dB} R} \quad . \tag{5}$$

This method has been verified in practice in the set-up shown in Fig. 4 and the verification results are presented in Table 4.

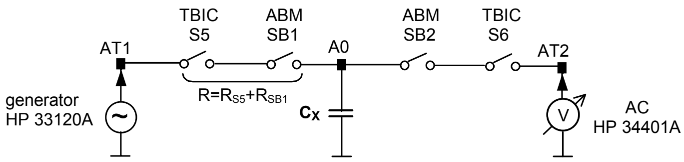

Fig. 4. Measurement of capacitance by determining the cut-off frequency f_{3dB}

Table 4. Measurement of capacitance by determining the cut-off frequency $f_{3\ dB}$

C_{nom} [nF]		10	100	1000	10000
f_{3dB} [kHz]		17,136	1,7593	0,17592	0,017254
R=1,0788 kΩ (HP 34401A)	C_x [nF]	8,609	83,86	838,6	8551
	δ [%]	-14	-16	-16	-15
R=0,9046 kΩ (calibration)	C_x [nF]	10,267	100,01	1000,1	10200
	δ [%]	2,7	0,00	0,01	2,0

Because the STA400 has a unipolar power supply, the signal from the generator had a DC component +400 mV and an output voltage AC 100 mV. The resistance R of the switches in modules TBIC and ABM was determined by direct measurement with the HP 34401A multimeter and through calibration with a known capacitor of C=100 nF. Large errors, in the case of using in calculations the resistances of TBIC and ABM switches measured directly with the multimeter, are caused by changes on this resistance under the influence of voltage changes across the bus switches.

A considerable improvement of accuracy can be obtained by measuring the resistance of TBIC and ABM switches and taking into account the DC component or by calibrating the circuit through the measurement of the cut-of frequency at one known capacitance value C and determining the value of R from relation (5).

A better accuracy of capacitance measurement with the use of the bus can be ensured by a method based on the use of an AC voltage source [6] and indirect determination of the current, through measurement of voltage across an additional series-connected standard resistor R_w.

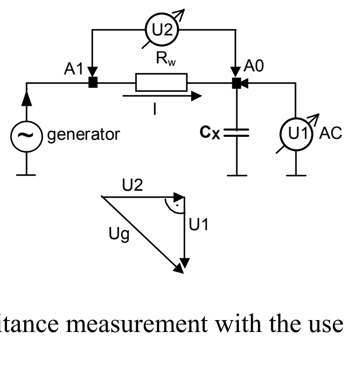

Fig. 5. Principle of capacitance measurement with the use of a standard resistor R_w

The essence of the method is shown in Fig. 5 along with a vector diagram of voltages, where U_g is the voltage from the generator and voltages U_2 and U_1 – across the resistor and capacitor, respectively. Assuming that the capacitor is lossless and that voltage U_1 lags by 90 degrees behind the current, we can determine U_2 from the following relation:

$$U_2 = \sqrt{(U_g^2 - U_1^2)} \quad . \tag{6}$$

Knowing U_2 we can calculate the capacitance value from

$$C_x = \frac{1}{2\pi \cdot f \cdot Z} \quad , \tag{7}$$

where Z is

$$Z = \frac{U_1}{I} = \frac{U_1 R_w}{U_2} \quad . \tag{8}$$

This method has been verified in practice in the circuit shown in Fig. 6.

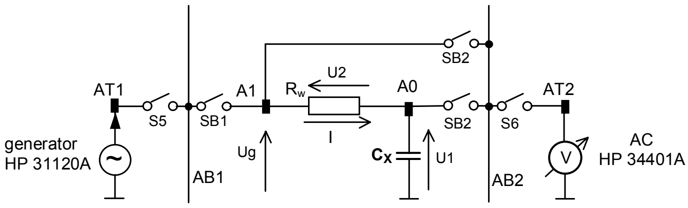

Fig. 6. Circuit for the measurement of capacitance with the use of an additional standard resistor R_w

In this circuit, the capacitor is connected to terminal A0 of the integrated circuit and the standard resistor R_w between terminals A1 and A0. In this case, voltage U_2 is the vector difference between the voltage U_{A1} measured at terminal A1 and voltage U_{A0} measured at terminal A0, hence the sought-after capacitance value can be determined from the relation below

$$C_x = \frac{\sqrt{(U_{A1}^2 - U_{A0}^2)}}{2 \cdot \pi \cdot f \cdot R_w \cdot U_{A0}} \quad . \tag{9}$$

The results of the verification of the method for R_w = 1 kΩ and two frequencies 1 kHz and 10 kHz are shown in Table 5.

Table 5. Measurement of capacitance with indirect determination of current

f [Hz]	R_w [Ω]	C_{nom} [nF]	10	100	1000	10000
1000	1000	C_x [nF]	-	100,47	1005,3	10051
		δ [%]	-	0,47	0,53	0,51
10000	1000	C_x [nF]	10,10	100,40	1000,5	-
		δ [%]	0,97	0,40	0,05	-

In comparison with the previous method, this one provides greater accuracy, at the level of better than 1% for capacitances in the range 10 nF to 10 μF. As the standard resistor R_w and the capacitance under measurement C_x form a low-pass filter, it is essential to choose an appropriate measuring frequency. At frequencies considerably lower than the 3 dB cut-off frequency, the voltage at terminal A0 is close to that at terminal A1 ($U_{A0} \approx U_{A1}$), while at frequencies much higher than the cut-off frequency, voltage U_{A0} is close to zero. Thus, to ensure an adequate accuracy [7], the measurement frequency should fulfill the condition $0{,}2\ f_{3dB} < f < 20\ f_{3dB}$.

V. Inductance measurements

In search for simple methods of inductance measurements with the use of the IEEE 1149.4 bus, the method of capacitance measurement with indirect determination of current was adapted. The inductance to be measured L_x was connected in place of the capacitor C_x (Fig.7).The expression for the inductance value has been derived in an analogous way as in the case of capacitance measurements. The inductance value searched for is given by

$$L_x = \frac{R_w \cdot U_{A0}}{2 \cdot \pi \cdot f \cdot \sqrt{(U_{A1}^2 - U_{A0}^2)}} \quad . \tag{10}$$

The results of experimental verification of the method for a frequency of 10 kHz and two values of the standard resistor R_w = 100 Ω and R_w = 1 kΩ are presented in Table 6. Standard inductances from the range of 300 μH to 30 mH were used.

Table 6. Inductance measurements with indirect determination of current

f [Hz]	R_w [Ω]	L_{nom} [mH]	0,3	1	3	10	30
10000	100	L_x [mH]	0,3008	0,9833	2,889	9,758	-
		δ [%]	0,28	-1,7	-3,7	-2,4	-
10000	1000	L_x [mH]	-	1,019	2,978	9,934	29,58
		δ [%]	-	1,9	-0,74	-0,66	-1,4

As the measured inductance L_x and the standard resistor R_w form a low-pass filter, the choice of a proper measurement frequency for a given R_w is essential, similarly as in the case of capacitance measurements, such that the measured voltage U_{A0} is significantly different both from zero and from U_{A1}.

VI. Conclusions

The investigations have shown the possibility of using the IEEE 1149.4 bus for measurements of RLC element values, by connecting them between terminals of the STA400 integrated circuit. These integrated circuits can be used for the measurement of resistors with an accuracy better than 0.5% and to measure capacitors with a low loss factor with an accuracy better than 1% for the method with indirect current measurement and a few percent for the 3dB cut-off frequency method. In the case of inductances with low loss factors it is possible to achieve an accuracy better than 4%.
An advantage of the proposed methods is their simplicity – to measure a resistance a DC current source and a voltmeter suffice, whilst for the measurement of capacitance and inductance it is required to use a variable-frequency generator and an AC voltmeter plus, if necessary, an additional standard resistor. The accuracies of measurement obtained are sufficient for production requirements.
Tests have also shown some shortcomings of STA400 integrated circuits, above all the large resistance of switches in the analog bus, nonlinearly changing as a function of the applied voltage, as well as the presence of a parasitic resistance between the circuit terminal and the SG switch, causing errors in the measurement of voltages in the ABM module connected to ground by the SG switch.

References

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