A Built-in Self-Check Method for Multi-Channel Measurement Systems

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Abstract – Signature analysis techniques have become extremely popular in digital systems testing due to such advantages as simplicity, small amount of additional circuitry, and small degree of error masking. In this paper the signature analysis techniques are applied to mixed (analog-to-digital) systems testing. The general case of multi-channel measurement system is considered.

Keywords – BIST, ADC, Signature Analysis

1. Introduction

The method of "reference signals" has been standard method used in practice for built-in self-check in measurement systems mainly because of its small additional hardware. In this method, inputs of a system (inputs of channels – for multi-channel system) are fed by a sequence of reference analog signals. The system measures these signals and estimates difference (static error) between expected and actual output values for every channel and every reference signal. If all of these errors do not exceed appropriate tolerances then the system is assumed to operate properly. In some variations of this method the additive and multiplicative static errors (rather than the overall system static error) are estimated and compared to the tolerances [1].

The more reference signals are applied to the system, the more hidden failures may be detected. But the number of the references influences the amount of memory to store reference codes, and hence the overall reliability. Moreover, every additional error assessment increases the overall testing time.

We examine a self-check method, which also employs reference signals, but measurement results (static errors) are not estimated directly. All of them are compressed into one short "signature", which is compared with the reference signature of a fault-free system. If the difference between them falls into the predefined range, then the system is assumed to be fault free. This approach accelerates checking and minimizes storage requirements for the circuit under test while the probability of error masking is slightly increased.

2. The problem statement

Let us consider a multi-channel measurement system (MCMS) with r channels represented in Fig. 1. Here $K_1,\dots,K_r$ – are channels of a system; MCU – is a Microcontroller Unit; IU – is an interface unit; $RSS_1,\dots,RSS_r$ – are reference signal sources; $x_1^o,\dots,x_r^o$ and $x_1,\dots,x_r$ – are the reference and actual input signals respectively. Every RRS_i can output periodic reference signal feeding K_i, i=1,…,r.

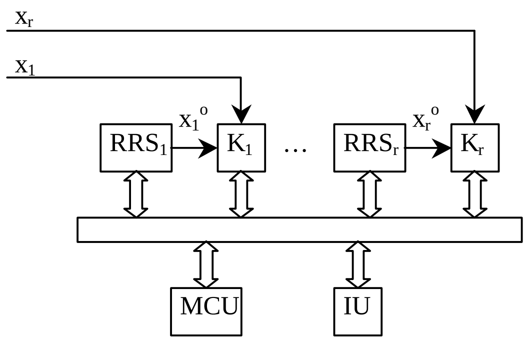

Fig. 1.

Let m_j be a number of different values of x_j^o required to manifest any fault from a given class in K_j on its output. And let x_{ji}^o be the value of x_j^o at time t_i and $y_{ji} = [x_{ji}^o + 0.5q_j] + \delta_{ji} = y_{ji}^o + \delta_{ji}$ be the corresponding output code. Here q_j is a quantization step in channel K_j, and [a] means integer of a; y_{ji}^o is the "reference" output code; δ_{ji} is a static error when measuring the signal x_{ji}^o by the channel K_j. We will denote the upper and lower tolerances on this error as $\delta_{ji}^\wedge$ and $\delta_{ji}^\vee$. The MCMS operates properly if

$$\delta_{ji}^\vee \le \delta_{ji} \le \delta_{ji}^\wedge,\ j=1,\dots,r,\ i=1,\dots,m_j \qquad (1)$$

and is faulty otherwise, because (1) will not hold at least for one combination of i and j for any failure from the given class.

From the practical point of view we will check the following condition rather than (1):

$y_{ji}^{\vee} \le y_{ji} \le y_{ji}^{\wedge}$, where $y_{ji}^{\vee} = y_{ji}^{o} + \delta_{ji}^{\vee}$, $y_{ji}^{\wedge} = y_{ji}^{o} + \delta_{ji}^{\wedge}$.

It is required to check MCMS in Fig. 1 as fast as possible and having small storage requirements (provided given probability of error masking).

3. The checking technique

To solve this problem, instead of comparing y_{ji} with the tolerances we will add all y_{ji} modulo $L=2^{l}$ in the MCU. Here l is the number of digits in arithmetic-logical unit of MCU. At all additions the sum will be

$$R = \left(\sum_{j=1}^{r} \sum_{i=1}^{m_j} y_{ji} \right) \bmod L \cdot$$ Denoting

$$B = \left(\sum_{j=1}^{r} \sum_{i=1}^{m_j} y_{ji}^{o} \right) \bmod L + \left(\sum_{j=1}^{r} \sum_{i=1}^{m_j} d_{ji} \right) \bmod L$$ yields

$$R = B \bmod L \qquad (2)$$

Let the following condition be satisfied for the modulo L:

$$\Delta^{\wedge} + |\Delta^{\vee}| < L \qquad (3)$$

where $\Delta^{\wedge} = \sum_{j=1}^{r} \sum_{i=1}^{m_j} d_{ji}^{\wedge}$, $\Delta^{\vee} = \sum_{j=1}^{r} \sum_{i=1}^{m_j} d_{ji}^{\vee}$. Then $\Delta^{\wedge} \bmod L = \Delta$, $|\Delta^{\vee}| \bmod L = |\Delta^{\vee}|$ and for the properly operating MCMS

$$B^{\vee} = \left(\sum_{j=1}^{r} \sum_{i=1}^{m_j} y_{ji}^{o} \right) \bmod L - |\Delta^{\vee}| \le B \le$$
$$\le B = \left(\sum_{j=1}^{r} \sum_{i=1}^{m_j} y_{ji}^{o} \right) \bmod L + \Delta^{\wedge} \qquad (4)$$

Let us determine the boundaries on R. Three cases are possible here depending on values of $B^{\vee}$ and $B^{\wedge}$ (which are known for the MCMS a priori):

1) $B^{\vee} \ge 0$, $B^{\wedge} < L$, then from (2) and (4)

$$B^{\vee} \le R \le B^{\wedge} \qquad (5)$$

2) $B^{\vee} > 0$, $B^{\wedge} > L$, then

$$0 \le R \le B^{\wedge} \bmod L \text{ or } B^{\vee} \le R \le (L-1) \qquad (6)$$

3) $B^{\vee} < 0$, $0 < B^{\wedge} < L$, then

$$0 \le R \le B^{\wedge} \text{ or } B^{\vee} \bmod L \le R \le (L-1) \qquad (7)$$

Therefore, if MCMS operates properly, then one of (5) – (7) holds. The converse is generally true with some probability degree. It will be shown later on that this probability is quite large.

Hence, after the value of R is calculated in the MCU one of the conditions (5) to (7) is verified. It the condition does not hold (which is possible since (3)), then the MCMS is definitely faulty. Otherwise, the MCMS is assumed to be fault free. Because we verify only one condition, then the testing time and hardware overhead are small.

Let us define the probability of detecting errors, D for this method. Apparently, D=1-p, where p is the error masking probability. Let p_1 and p_2 be the probabilities of masking errors related to the addition and division with respect to modulo L accordingly. It can be shown that

$$p_1 \le (|\Delta^{\vee}| + \Delta^{\wedge}) / 2d = \left(\sum_{j=1}^{r} \sum_{i=1}^{m_j} (|d_{ji}^{\vee}| + d_{ji}^{\wedge}) \right) / 2d$$

where δ is the maximum allowable error in a channel, which is defined by the number of output digits in the channel, and

$$p_2 = (2^{2dm-l} - 1)/(2^{2dm} - r)$$

where m is max m_j for all j. If m is quite large then $p_2=2^{-l}$.

For example, in case of bipolar channels with $\delta_{ji}^{\wedge} = \delta_{ji}^{\vee} = 1$ and quite large m

$$D \ge 1 - (2^{-l} + m/(2^{n} - 1))$$

For instance, r=4, m_j=16, j=1,…,4, n=l=16 yields D ≥ 0.99902.

4. Conclusion

We have considered a built-in self-check method for multi-channel measurement systems that is based on compacting output codes of channels into a short signature and comparing this signature with tolerances. The system is assumed to be fault free, if the verification condition holds for the signature. The length of the signature is defined by the error tolerances in the channels.

The reliability of detecting errors is evaluated. If the number of measurements is relatively large then the reliability depends only on the allowable error tolerances in the channels and on the length of the signature. For instance, in the case of 4-channel measurement system, which is fed by 16 reference signals, the reliability is not less then 0.99902.

In case of the sequential A-to-D converters implementation of the method is quite simple. The binary counter that is normally comprised in such ADCs can be used as a signature compacting scheme.

The proposed method can also be used for signature testing of analog circuits by means of the precise and fault free ADC. The analog circuit is supposed to be fed by the changing reference signals.

Practical implementation of the method is limited to the systems where reference signals can be obtained by deviation of some system parameters. For example, in RLC-meters it can be frequency of the signal, which feeds the impedance being measured, or the phase of this signal, etc.

5. References

[1] A. Gookin, "A Fast Reading High Resolution Voltmeter that Calibrates Itself Automatically", Hewlett Packard Journal, 1977, vol. 28, No 6, pp. 2-10.