OBIST STRATEGY VERSUS PARAMETRIC TEST EFFICIENCY EVALUATION

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Abstract. This paper deals with the verification of efficiency of the novel on-chip OBIST (Oscillation Built-In Self Test) strategy by comparison the fault coverage in selected types of active analog integrated filters. Fault coverage obtained by OBIST approach was compared to fault coverage results obtained by the measurement and evaluation of filters' selected parameters.

Keywords. Oscillation Built-In Self Test, on-chip OBIST strategy, parametric test, catastrophic faults, analog BIST

1 Introduction

The integration density in today's nanometer scaled technologies is rapidly increased that causes testability problems in complex integrated systems and greater demands on the test methods and equipment. Production test of analog ICs is typically based on the external measurement of main parameters indicated in the circuit specifications. Such test is rather easy but slow and time consuming, and in some cases, it may not be successful in covering some catastrophic faults. Additionally, it requires sophisticated test equipment and in complex mixed systems, it might face accessibility problems to some cores. Built-In Self Test (BIST) of complex analog and mixed-signal integrated systems could be still one of the most convenient or only proper and possible test approaches in some applications [1]. However, the main disadvantage of BIST approaches is an area overhead, which increases total production costs.

The main goal of the work presented in this paper is the comparison of the OBIST approach efficiency in covering the catastrophic faults in selected type of analog active integrated filters to the fault coverage results obtained by the filter parameters measurement.

2 On-chip OBIST for active analog filters

The OBIST test strategy, described in [2], has been applied to three types of active analog integrated filters: Sallen-Key low-pass and high-pass filters as well as a state-variable active filter. The selected analog filters as well as the dedicated additional test hardware for on-chip evaluation process were designed in 0.35µm CMOS technology. The OBIST strategy for Sallen-Key topology of low-pass filter has been described in [1] and [3]. OBIST for Sallen-Key high-pass filter state-variable active filter is presented in the next section of this paper. Obtained results are summarized in Section 3. In the last section, the fault coverage of tested filters through the obtained results is discussed.

2.1 Sallen-Key low pass filter

Sallen-Key topology of active low-pass filter can be converted to an oscillator by inserting a positive feedback network containing a simple high-pass RC delay or by relocating the filter poles onto the imaginary axis (modifying parameter values of some passive components) [4].

Figure 1 shows a circuit diagram of Sallen-Key active low-pass filter transformed into an oscillator through additional T-gates controlled by a control logic (CL) block. In the operating mode, the input and output terminals are connected to the respective nodes of a complex circuit. During the test mode, the tested filter is disconnected from the rest of a circuit, and a positive feedback network consisting of a high-gain inverter (gray color) is inserted [4]. The inverter ensures the phase shift of 180° and the tested circuit induces a delay, which controls the sustained oscillation frequency [4].

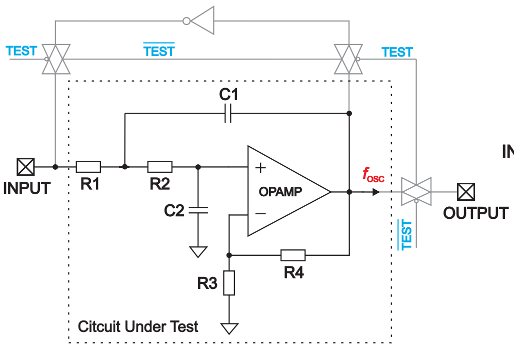

Figure 1: Sallen-Key low-pass filter.

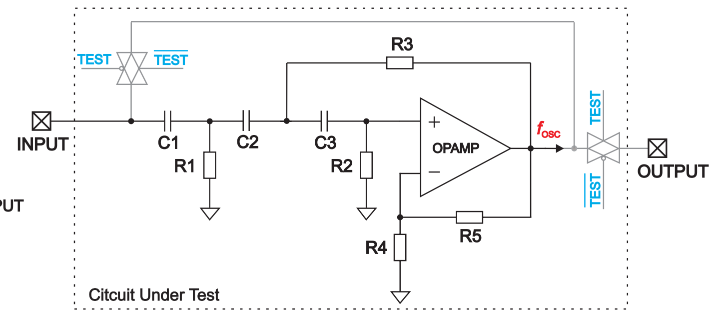

Figure 2: Sallen-Key high-pass filter.

2.2 Sallen-Key high-pass filter

Sallen-Key topology of high-pass filter transformed into an oscillator is shown in Figure 2. The selected topology can by transform to an oscillator by shortcutting the input and output of the filter in order to establish a positive feedback network [4]. For this purpose, in our case we used T-gates to make this short. T-gates are again controlled by the control logic.

2.3 State-variable filter under test

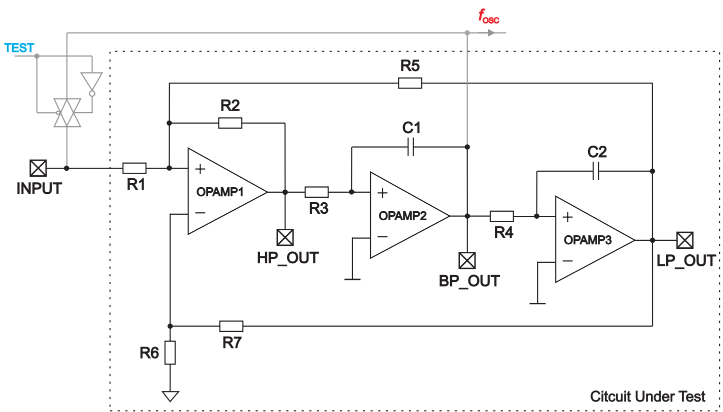

Figure 3: State-variable active filter

The state-variable active filter actually consists of low-pass, high-pass and band-pass filters. In this work, only the band-pass output of the tested circuit has been considered. The basic approach to converting this filter to an oscillator is to establish a positive feedback loop with a zero crossing detector. Zero crossing detector is used to ensure a high-gain and guarantee the sustained oscillation, however, is not necessary if the filter gain is greater then unity. The oscillation frequency will be equal to the center frequency of the filter, where the lead and lag phase shifts cancel each other out [4]. The circuit diagram of the state-variable filter, transformed by additional circuitry (gray) into the oscillation BIST, is depicted in Figure 3.

2.4 On-chip evaluation process

The oscillation frequency of filters was evaluated by countering a number of oscillation pulses exhibited by the CUT during the time interval generated by an on-chip Schmitt reference oscillator [4]. Block diagram of the proposed on-chip test strategy, based on the oscillation frequency evaluation and PASS/FAIL decision process, is illustrated in Figure 4. In test mode, counter counts the oscillation pulses from FUT during the time interval generated by Schmitt oscillator and frequency divider. When the counter stops counting, the control logic (CL) evaluates the counter, and the pass/fail signal indicating the CUT status will be generated. Detailed description of the proposed test strategy and the relation between the limits of tolerance band and the initial/final state of the counter are presented in [4].

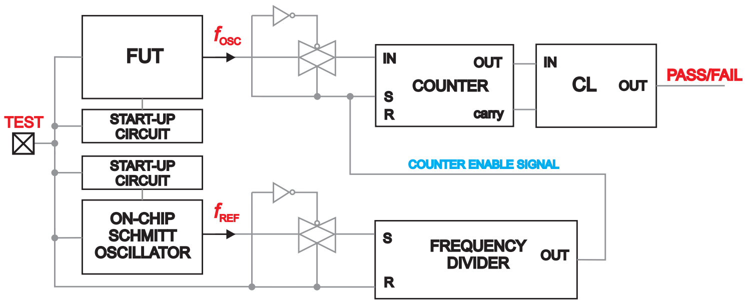

Figure 4: The proposed OBIST for integrated analog active filters

3 Achieved results

In our work, we have compared the fault coverage of the implemented OBIST strategy to the fault coverage results obtained by measurement of the circuit main parameters. For this purpose, the following filter parameters have been measured and evaluated in the operating mode: the cut-off frequency, ripple in the pass band, DC gain in pass band and group delay, while the oscillation frequency of the filter was monitored in the test mode. For the efficiency verification, four types of catastrophic faults (shorts, opens, floating gates and gate-oxide shorts) were considered in the circuits under test. Short and open faults were injected in all connection paths, while floating gates (FG) and gate-oxide shorts (GOS) were inserted in all transistors forming the OPAMPs used in the filters.

The total fault coverage achieved for the Sallen-Key low-pass filter by the OBIST strategy is summarized in Table 1. The worst fault coverage of 82.35 % was observed for short faults, while the best fault coverage results were achieved for opens considered in the operational amplifier. Moreover, fault coverage of 84.54 % was achieved for all faults considered and injected in the amplifier, and the best fault coverage of 99 % was achieved on the filters top level. Finally, the total fault coverage of 91.46 % was obtained for all faults considered in the whole filter.

Table 2, shows the fault coverage results that were achieved by measuring the Sallen-Key low-pass filter main parameters. The total fault coverage achieved for the filter by the parametric test is 84.83 % that is about 6.6 % lower than the efficiency of the OBIST strategy applied to the same circuit. It is also important to notice that the total fault coverage was obtained by monitoring four selected parameters of the filter under test.

Table 1: OBIST efficiency for Sallen-Key LPF

Faults	inserted	detected	Fault coverage
OPAMP			
Shorts	68	56	82.35 %
Opens	24	23	95.83 %
FGs	9	8	88.88 %
GOSs	9	6	66.66 %
FILTER TOP LEVEL			
Shorts	84	83	98.8 %
Opens	17	17	100 %

Table 2: Efficiency of parametric test for LPF

Faults	inserted	detected	Fault coverage
OPAMP			
Shorts	68	51	75 %
Opens	24	18	75 %
FGs	9	7	77.77 %
GOSs	9	6	66.66 %
FILTER TOP LEVEL			
Shorts	84	80	95.23 %
Opens	17	17	100 %

The total fault coverage achieved for Sallen-Key high-pass filter by the OBIST strategy is summarized in Table 3. The worst fault coverage was observed for short faults, where the fault coverage of 79.42% and 85.41% was obtained for short faults considered in the operational amplifier and on the filter top lever devices, respectively. Very high fault coverage was observed for opens, floating gates and gate oxide shorts considered in the HPF. The total fault coverage of 86.64 % was obtained for all faults considered in the whole high-pass filter by OBIST strategy.

Table 3: OBIST efficiency for Sallen-Key HPF

Faults	inserted	detected	Fault coverage
OPAMP			
Shorts	68	54	79.42 %
Opens	24	23	95.83 %
FGs	9	9	100 %
GOSs	9	9	100 %
FILTER TOP LEVEL			
Shorts	144	122	85.41%
Opens	23	23	100 %
Total	**277**	**240**	**86.64 %**

Table 4: Efficiency of parametric test for Sallen-Key HPF

		A_O		*ripple*		f_C		*group delay*	
Faults	inserted	detected	Fault coverage	detected	Fault coverage	detected	Fault coverage	detected	Fault coverage
OPAMP 1									
Shorts	68	55	80.88 %	54	79.41 %	39	57.35 %	58	85.29 %
Opens	24	12	91.67 %	22	91.67 %	19	79.17 %	20	83.33 %
FGs	9	8	88.88 %	8	88.88 %	7	77.77 %	8	88.88 %
GOSs	9	7	77.77 %	7	77.77 %	6	66.66 %	8	88.88 %
TOP LEVEL									
Shorts	144	110	76.39 %	107	74.31 %	88	61.11 %	111	77.08 %
Opens	25	20	80 %	21	84 %	20	80 %	21	84 %
Total	**279**	**222**	**79.57 %**	**219**	**78.49 %**	**179**	**64.16 %**	**226**	**81 %**

Table 4, shows the fault coverage achieved by measurement of the high-pass filter main parameters. If only one of the main parameters was measured, in all cases the total fault coverage in the high-pass filter would have been lower than the fault coverage obtained by on-chip OBIST strategy. The best fault coverage of 81% was achieved by measuring the group delay of the selected high-pass filter.

The total fault coverage for state-variable filter obtained by OBIST strategy and parametric test are summarized in the Table 5 and 6, respectively.

Table 5: OBIST efficiency for State-variable filter

Faults	inserted	detected	Fault coverage
OPAMP 1			
Shorts	68	45	66.18 %
Opens	24	17	70.83 %
FGs	9	7	77.77 %
GOSs	9	5	55.55 %
OPAMP 2			
Shorts	68	52	76.48 %
Opens	24	18	75 %
FGs	9	9	100 %
GOSs	9	4	44.44 %
OPAMP 3			
Shorts	68	47	69.18 %
Opens	24	20	83.33 %
FGs	9	7	77.77 %
GOSs	9	5	55.55 %
FILTER TOP LEVEL			
Shorts	176	143	81.25 %
Opens	31	29	93.55 %
Total	**537**	**408**	**84.64 %**

Table 6: Efficiency of parametric test for State-variable filter

		A_O		f_C		f_L		f_H	
Faults	**inserted**	**detected**	**Fault coverage**	**detected**	**Fault coverage**	**detected**	**Fault coverage**	**detected**	**Fault coverage**
OPAMP 1									
Shorts	68	55	80.88 %	45	66.17 %	32	47.06 %	44	64.07 %
Opens	23	18	78.26 %	17	73.91 %	15	65.21 %	16	69.56 %
FGs	9	7	77.77 %	7	77.77 %	5	55.55 %	7	77.77 %
GOSs	9	8	88.88 %	6	66.66 %	5	55.55 %	5	55.55 %
OPAMP 2									
Shorts	68	68	100 %	67	98.52 %	59	86.76 %	68	100 %
Opens	23	23	100 %	20	86.96 %	15	65.21 %	19	82.6 %
FGs	9	8	88.88 %	6	66.66 %	5	55.55 %	5	55.55 %
GOSs	9	8	88.88 %	9	100 %	8	88.88 %	9	100 %
OPAMP 3									
Shorts	68	68	100 %	68	100 %	68	100 %	68	100 %
Opens	23	23	100 %	23	100 %	23	100 %	23	100 %
FGs	9	9	100 %	9	100 %	6	66.66 %	9	100 %
GOSs	9	9	100 %	9	100 %	8	88.88 %	8	88.88 %
TOP LEVEL									
Shorts	216	203	93.98 %	169	78.24 %	171	79.16 %	175	81.01 %
Opens	30	30	100 %	25	83.33 %	25	83.33 %	28	93.33 %
Total	**537**	**408**	**93.71 %**	**480**	**83.77 %**	**445**	**77.66 %**	**484**	**84.46 %**

For the band pass output of the state-variable filter, the DC gain (A_O), center frequency (f_C), low cut-off frequency (f_L) and high cut-off frequency (f_H) have been measured and evaluated within the parametric test. The best fault coverage of 93.71 % was obtained by measuring the A_O parameter of the filter. The lowest fault coverage of 77.66 % was obtained by evaluating the low cut-off frequency.

4 Conclusion

Two different test approaches have been implemented and compared in terms of their efficiency in the covering catastrophic faults present in integrated analog filters. Those two methods are oscillation-based BIST and parametric test (main filters' parameters evaluated). For the efficiency evaluation, four different catastrophic fault types were considered and injected in the tested filters.

The experimental results indicate that OBIST strategy can achieved very high fault coverage of hard-detectable catastrophic faults, which is a very favorable result. Although in same cases, the fault coverage obtained by monitoring the filter parameters was lower, the fault coverage obtained by OBIST method represents still a satisfactory result. The main advantage of the OBIST method is an easy implementation and also possible on-chip realization. On the other hand, classical parametric test is usually time consuming process, which requires advanced ATE that might be rather costly. Therefore, taking into account the results obtained within this work, the OBIST method using the on-chip reference oscillator could represent an advantageous alternative and an appropriate choice for testing the active analog integrated filters, especially if being embedded in complex mixed-signal systems.

Future research towards PhD Thesis will be mainly focused on the analysis of applicability of OBIST for analog integrated circuits realized in nanotechnology. Currently, for this purpose, selected analog and mixed-signal experimental circuits are under design in 90 nm CMOS technology. The R-2R D/A converter was designed, employing an operational amplifier with input voltage offset cancellation technique [5]. The reference oscillator that is a basic block of on-chip OBIST strategy will also be used for realization of a test vector generator for BIST of binary-weighted D/A converters.

One of our future tasks will also be finding a possible dependence between the oscillation frequency value and fault coverage, as well as any proposal for a methodology for its determination. The final task will be verification of the proposed test strategies on real integrated circuits designed in 90nm technology.

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