Bias variation detection in RF amplifiers using differential OBIST

M Ballot and T Stander
Carl and Emily Fuchs Institute for Microelectronics, Dept. EEC Engineering, University of Pretoria, Pretoria, South Africa
E-mail: max.ballot@ieee.org, tinus.stander@up.ac.za

Abstract. Oscillation-based built-in self-testing with differential power detection has been shown to be a promising method for detecting degradation in radio frequency (RF) amplifiers. We demonstrate the use of the method to detect supply voltage decrease and base current variation. The efficacy of the approach is verified using simulated results of a 2.4 GHz low-noise amplifier (LNA). It is shown that these variations can be detected by using only power detection.

1. Introduction
Oscillation-based testing (OBT) [1] is a method of circuit testing that does not require test inputs. The device under test (DUT) is switched into an astable feedback loop, and the resulting oscillation frequency \( f_0 \) and amplitude \( A \) measured and compared to those of a nominal circuit, with variation off nominal values \( \Delta f_0 \) and \( \Delta A \) interpreted as indicators of circuit faults. Oscillation-based built-in self-testing (OBIST) [2] extends on this, where \( f_0 \) and \( A \) are monitored in-system or in-circuit without external test equipment. Some advanced in OBT at radio frequency (RF) [3] and mm-wave [4] frequencies have been proposed, but these still require test equipment to monitor the output. In contrast, built-in self-testing (BIST) at RF exploits in-system power detection [5, 6, 7] with built-in sources. To make RF OBT a built-in test, it has recently been demonstrated [8] that \( \Delta f_0 \) variation may be detected with a frequency selective power detection, with \( \Delta A \) distinguished by switching between two feedback loops. This work was expanded on in [9], where the natural frequency selectivity of the OBIST feedback loop was used as a frequency discriminator, using power detectors at the input (PD_{in}) and output (PD_{out}) of the feedback loop. In this way, \( \Delta PD = PD_{in} - PD_{out} \) is used to detect \( \Delta f_0 \) thus eliminating the need for digitisation of RF signals. Amplifier gain reduction was successfully detected in this way.

In this work, we propose to extend on the work in [9], by investigating the detection of a decrease in supply voltage (\( V_{cc} \)) and variation base current (\( I_b \)), with the circuit proposed in [9].

2. Circuit
Fig. 1 shows the differential detection OBIST circuit for a 2.4 GHz LNA proposed in [9]. The LNA is designed using an Infineon BFP843 HBT and a MACOM MASWSS0115 switches. The small-signal characteristics of switches are included in circuit simulation and the detectors are modelled as 50 \( \Omega \) terminations. \( C_{mi,o} \) and \( L_{mi,o} \) are the matching elements, with \( L_{mi,o} \) acting
as RF chokes and $C_{mi,o}$ as RF decoupling caps as well. The OBIST circuit uses a Hartley tank, $C_I$ and $L_{f1,2}$, in the feedback loop, which creates phase shift from the output to the input of the LNA, and simultaneously acts as a frequency discriminator for $\Delta PD$. The switches switch the system between normal operation (feedback disconnected) and OBIST (loop connected, DUT disconnected from source and load). The power detectors at the input (PD$_{in}$) and output (PD$_{out}$) of the amplifier measure RF power and convert it to a direct current (DC) voltage suitable for low rate digitization. The power detectors also load the tank, reducing the Q-factor of the tank, which results in larger variations in $f_0$.

![Differential detection OBIST schematic](image)

**Figure 1.** Differential detection OBIST schematic. [9]

3. Results

3.1. LNA performance

The LNA is simulated in Keysight ADS, using the linear S-parameter solver, to gauge the impact of OBIST circuitry on LNA performance. Fig. 2 shows that the gain decreases from 20.5 dB to 19.6 dB at 2.45 GHz, while the noise figure (NF) increases from 1.46 dB to 2 dB, as shown in Fig. 3.
3.2. **OBIST results**

To extend the investigation in gain variation on [9], Keysight ADS’s harmonic balance solver (which converged in all cases with negligible residual error) was used to determine the effect of bias current $I_b$ and bias voltage $V_{cc}$ variation on $\Delta f_0$ and, consequently, $\Delta PD$.

Fig. 4 shows that $PD_{out}$ is proportional to $I_b$, and that there is significant variation from the nominal value at $I_b = 27 \, \mu A$. Fig. 5 shows that $f_0$ changes with $I_b$ and that the ratio between the input and output power changes proportional to $f_0$.

Fig. 6 shows the output power compared to a decrease in $V_{cc}$, from the nominal value of $V_{cc} = 1.8 \, V$. The figure shows that an overall decrease in output power is expected, but that the decline is not monotone. Fig. 7 shows the change in $f_0$ due to a decrease in $V_{cc}$. A clear shift $f_0$ is evident, and is also reflected in $\Delta PD$.

---

**Figure 2.** OBIST circuitry effect on nominal amplification.

**Figure 3.** OBIST circuitry effect on nominal NF.

**Figure 4.** Variation in power at output detector due to $I_b$ variation.

**Figure 5.** $f_0$ variation and differential detection due to $I_b$ variation.

**Figure 6.** Decrease in power at output detector due to $V_{cc}$ reduction.

**Figure 7.** $f_0$ variation and differential detection due to $V_{cc}$ reduction.
4. Conclusion

We extend on the gain variation detection results in [9] to show that differential power detection OBIST can be used to detect variation in $V_{cc}$ and $I_b$, with minimal effect on LNA performance. The results show a direct relationship between $I_b$ variation, the oscillator’s output power, and power ratio of the power detectors. This indicates that a simple threshold detection on $PD_{out}$ is sufficient for diagnosis. Detection of $\Delta I_b$ is critical as it significantly affects gain, noise figure, and linearity of the LNA [10]. A decrease in $V_{cc}$ can also be detected with threshold diagnosis, though without an indication of the severity. This lack of severity detection is due to the fact that neither $\Delta f_0$, $\Delta PD$, nor $PD_{out}$ vary monotonically with $V_{cc}$, therefore more complex diagnostics (such as machine learning classifiers using multiple oscillator circuit features) have to be applied. $V_{cc}$ on its own does not have as significant an effect on LNA performance as $I_b$ has, because it only significantly affects compression, and only affects gain as it approaches $V_{be(on)}$ [10, 11]. This is expected to be fully detectable with simple threshold detection on $PD_{out}$. Future work will validate this approach experimentally, and extend this analysis to broadband multi-tone oscillation testing, as well as testing of full receiver chains. The effect of process variation on fault detection will also be investigated, as demonstrated in [8].

References

[1] Arabi K and Kaminska B 1997 IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems 16 745–753 ISSN 02780070
[2] Arbet D, Stopjakova V, Majer L, Gyepes G and Nagy G 2013 IEEE Transactions on Nanotechnology 12 486–497 ISSN 1536-125X
[3] Goyal A, Swaminathan M, Chatterjee A, Howard D C and Cressler J D 2012 IEEE Transactions on Very Large Scale Integration (VLSI) Systems 20 1835–1848 ISSN 1063-8210
[4] Margalef-Rovira M, Barragan M J, Sharma E, Ferrari P, Pistono E and Bourdel S 2018 An oscillation-based test technique for on-chip testing of mm-wave phase shifters 2018 IEEE 36th VLSI Test Symposium (VTS) (IEEE) pp 1–6 ISBN 978-1-5386-3774-6
[5] Lahbib I, Doukkali M A, Descamps P, Gamand P, Kelma C and Tessson O 2014 International Journal of Microwave and Wireless Technologies 6 195–200 ISSN 1759-0787
[6] Xiaohua Fan, Onabajo M, Fernandez-Rodriguez F, Silva-Martinez J and Sanchez-Sinencio E 2008 IEEE Transactions on Circuits and Systems I: Regular Papers 55 1794–1804 ISSN 1549-8328
[7] Ryu J Y, Kim B and Sylla I 2006 IEEE Transactions on Instrumentation and Measurement 55 381–388 ISSN 0018-9456
[8] Nel H P, Stander T and Dualibe F C 2018 Built-In Oscillation-Based Self-Testing of a 2.4 GHz LNA in 0.35um CMOS 2018 25th IEEE International Conference on Electronics, Circuits and Systems (ICECS) (Bordeaux, France: IEEE) pp 837–840 ISBN 978-1-5386-9562-3
[9] Ballot M and Stander T 2019 Built-in Oscillation-Based Testing of RF Amplifier Gain using Differential Power Detection 2019 IEEE Radio and Antenna Days of the Indian Ocean (RADIO) (Réunion, France: IEEE) pp 1–2
[10] Liang Q, Niu G, Cressler J D, Taylor S and Harame D L 2002 Geometry and bias current optimization for SiGe HBT cascode low-noise amplifiers IEEE Radio Frequency Integrated Circuits Symposium, RFIC, Digest of Technical Papers pp 407–410 ISSN 0149645X
[11] Niu G, Liang Q, Cressler J D, Webster C S and Harame D L 2001 IEEE Transactions on Microwave Theory and Techniques 49 1558–1565 ISSN 00189480