On-line RF Built-In Self-Test using Noise Injection and Transmitter Signal Modulation by Phase Shifter

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***Abstract*— For on-chip self-test of radar ICs, loopback test using a signal feedback path from transmitter to receiver is state-of-the-art. Usually, such a loopback test is performed periodically after a number of application-mode chirps. The traditional loopback test has two drawbacks: it is performed intermittent to the application mode, not within the application mode. Moreover, it cannot detect the case that the attenuation from transmitter to receiver becomes too low due to defects on the IC, or due to targets very near to the antennas.**

This paper proposes an advanced loopback test not intermittent to the application, but during application mode. That way, spurious defects like transient faults (also known as Single Event Upsets) can be detected; moreover, an error-prone plausibility check of the received signal is avoided.

To detect receiver saturation due to near targets, modulating the transmitter output signal using a phase shifter is proposed.

Keywords—car radar; RF BIST; loopback test; Single Event Upsets (SEU)

I. Introduction

In car radar ICs, an important failure type are transient faults [1] which are caused e.g. by cosmic rays; they can either

- Change the contents of registers (flip-flops) which control the RF block (and thus e.g. modify a gain setting in the transmit or receive circuit), or
- Impact the RF block and disturb its internal signals.

Another main failure mechanism is increased crosstalk from the transmitter (Tx) to the receiver (Rx). In this case, the Rx may either become saturated and cannot correctly process reflected signals from real targets, or the noise level at the Rx is so high that objects cannot be reliably detected and/or the likelihood to detect "ghost targets" becomes unacceptably high. In both cases, these disturbances may impair the target identification:

- Existing objects are not detected
- Existing objects are detected, but their size, speed or distance is measured incorrectly
- Objects which actually don't exist are by mistake assumed to exist.

In most of the cases, the false target identification is corrected either by a repeated measurement, by running a built-in self-test or by a plausibility check of the RF block's output signal. A repeated measurement or a build-in self-test run take time, and they are not able to detect transient faults (Single Event Upsets), however. A plausibility check is error-prone, as it might by mistake reject correct signals, or might by mistake accept incorrect signals.

It is thus desirable to detect transient faults in real time, i.e. not to revert to above means of repeating the measurement, running a built-in self-test or by performing a plausibility check.

II. Transient fault detection by Noise injection

To perform RF BIST during application mode, not intermittent to it, this paper proposes a permanent feedback path with high attenuation from the Tx to the Rx. The attenuation is so high that the normal operation isn't disturbed. The transmit signal used for operation is mixed with deterministic phase noise. An approach for using noise for self-test of analog circuits was proposed in [2], for channel estimation of power networks it was discussed in [3]. The received signal is correlated with this phase noise, the result of this correlation is a DC voltage that is directly proportional to the Tx output power, the attenuation of the feedback path from Tx to Rx circuit, and the Rx gain.

Any disturbance of the Tx or the Rx can thus be detected in real time - it is thus a concurrent online test, in contrast to the non-concurrent (interleaved) state-of-the-art RF built-in self-test.

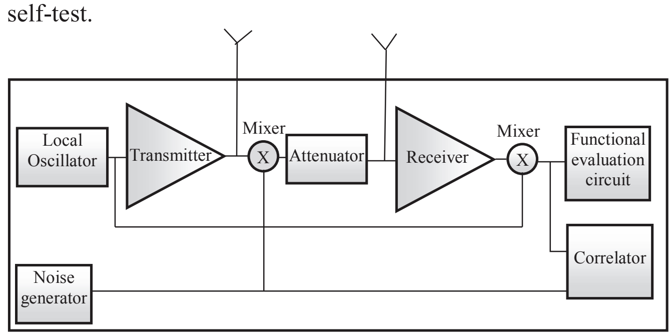

Figure 1: RF BIST using on-chip Tx-Rx Path

The proposal mainly targets detecting faults in the Tx and Rx (including their mixers) and their digital control circuits. In many cases, however, also defects of the Tx or Rx antennas can be detected because these defects will lead to an impedance mismatch of the Tx output or the Rx input; this mismatch would in many cases change the Tx output level or the input impedance of the Rx, thus changing the input level of the overlaid noise signal at the Rx.

III. Crosstalk detection

Increased crosstalk from Tx to Rx may be due to

- Dirt on the bumper or another part of the car that is covered both by the Tx main lobe or a side lobe, and the Rx main or side lobe.
- A loopback path intended for built-in self-test, which is intended to be active only during self-test, but which is activated by mistake in the application mode.
- A particle in the IC, or on the printed circuit board that leads to a low-attenuation path from Tx to Rx.
- A phase shifter in the Tx being active by mistake – or inactive by mistake – that leads to the main lobe or a side lobe of the Tx to reach the Rx antenna.

In car radar one-chip solutions, Frequency-Modulated Continuous Wave (FMCW) systems are state of the-art. In these systems, usually the same local oscillator signal is used as the Tx signal, and for mixing down the received signal. This means that a crosstalk signal as mentioned in above list is mixed down to a low frequency that only depends on the slope of the chirp (e.g. 2 GHz / 30 µs) and the travel time of the signal thru Tx, parasitic path and Rx. This time is in the order of a few ns, thus the baseband frequency of the crosstalk signal is only a few MHz.

Reducing the high 1/f noise in these systems mandates that the mixed down (IF) signal in the Rx is high-pass filtered. The high-pass cut-off frequency is usually chosen such that the signals of objects very near to the antennas are filtered out.

This all implies that a parasitic path cannot easily be detected from the receive signal, i.e. that saturating the Rx cannot be easily detected.

Modern automotive radar use phase shifters after the final Tx stage to enable MIMO techniques with channel coding to be able to distinguish the transmitted signals of different (usually 2-4) transmitters.

The paper proposes a means to modulate the transmitted signal additionally to the modulation performed by the transmitter's local oscillator. This modulation can be done by periodically switching, with a frequency sufficiently above the cut-off frequency of the high pass filter:

- A phase shifter or a phase rotator in the Tx.
- A control signal of the Tx that modifies the output amplitude of the Tx signal (e.g. a gain control). This amplitude modulation implies leads to a baseband spectrum with frequency components above the high-pass corner frequency.
- A path from Tx to antenna, that is needed e.g. for impedance matching of the antenna.

In all three cases, an element that already exists in the IC can be re-used. This is different to approaches using an on-chip attenuation path [4][5][6][7]).

In all three cases, the Tx signal contains frequency components that will be mixed down to frequencies that lie above the cut-off frequency of the high-pass filter.

This test is intended to be executed shortly before the beginning or after the end of each functional chirp, thus leading to a near-real-time test that is still fast enough to cover Single Event Upsets that disturb the actual application chirps.

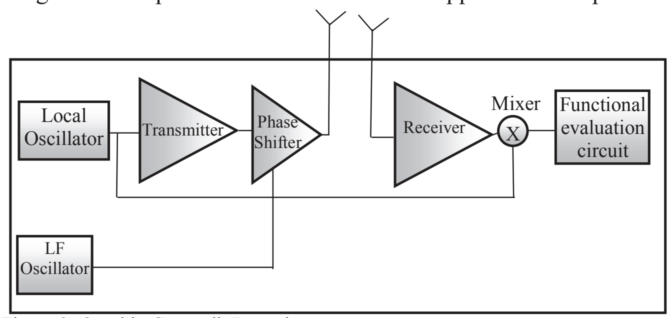

Figure 2: On-chip Crosstalk Detection

Conclusion

Two challenges for Functional Safety in car radar FMCW ICs were discussed: Traditional loopback BIST schemes are running intermittent to the application mode so that transient faults cannot be detected in real time, and very near targets cannot be directly detected.

These two problems are addressed by a dedicated high-attenuation feedback path and noise injection, and by modulation using e.g. the Tx's phase shifter.

With these two measures (that can perfectly be combined), Functional Safety can be increased significantly with very little overhead.

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