Low-cost digital solution for production test of ZigBee transmitters - Special Session “AMS-RF testing”

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***Abstract*— This paper describes a low-cost solution for production test of ZigBee transmitters. The solution relies on 1-bit acquisition of a 2.4GHz signal with a standard digital ATE channel using harmonic sampling. A dedicated post-processing algorithm is then applied on the low-frequency binary vector captured by the ATE to retrieve the RF signal characteristics and implement the tests specified by IEEE Std 802.15.4. Results collected in the industrial test environment on more than 1.5 thousand pieces of a ZigBee transceiver demonstrate the efficiency of the solution.**

Keywords*— *RF test; digital ATE; Industrial production test; Digital signal processing; Wireless communication; ZigBee

I. Introduction

RF devices are nowadays part of our society, especially devices dedicated to the Internet-of-Things (IoT) market. Production test of these devices is an important contributor to the global manufacturing cost, because it classically requires the use of an Automatic Test Equipment (ATE) equipped with expensive RF test resources. There is therefore a strong demand to reduce the testing cost of these devices.

An interesting approach is to develop solutions that can be applied on a digital ATE. A number of works can be found in the literature, e.g. based on the use of a reference transceiver accompanied by a FPGA to handle the interface between the reference transceiver and the digital ATE [1], or based on the use of a processor embedded in a radio SoC to implement self-test and provide low-frequency digital output [2], or defining a digital ATE system with multi-level drivers and comparators for direct modulation/demodulation of QAM signals [3]. Another approach is to rely on a oversampled 1-bit acquisition, as suggested in [4] for the demodulation of basic AM/FM schemes or in [5] for phase noise characterization of IF signals.

In this work, we target ZigBee transmitters and we describe a solution based on undersampled 1-bit acquisition of the 2.4GHz OQPSK signal using a standard digital ATE channel, associated with dedicated post-processing algorithms in order to implement the tests specified by IEEE Std 802.15.4™.

II. Proposed digital test solution

Our strategy to reduce RF testing costs is to propose new solutions that can be applied using low-cost standard digital tester channels instead of expensive RF tester channels. The basic principle illustrated in Fig.1 relies on 1-bit acquisition of the RF signal using the comparator and the latch comprised in a digital tester channel associated with a dedicated processing algorithm able to retrieve the RF signal characteristics from the captured binary vector and implement the different tests. Key challenges are (i) to determine appropriate conditions for the digital capture that permit to preserve the essential information contained in the RF signal and (ii) to define the dedicated processing algorithm able to retrieve the desired signal characteristics and implement the tests.

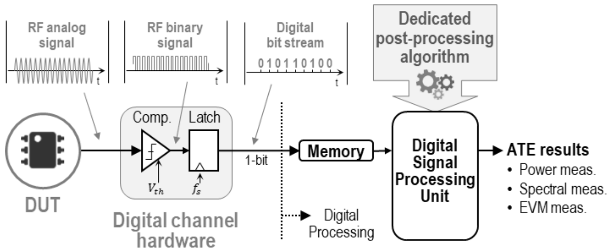

Fig. 1. Proposed digital approach for testing ZigBee transmitters

Regarding the digital capture, the fundamental concept is to use harmonic sampling in order to overcome the frequency limitation of the test equipment (typically 1.6GS/s for a standard digital ATE channel). The idea is to use a sampling frequency much lower than the signal frequency and to take advantage of the aliasing effect that creates a baseband image of the high-frequency signal. In the proposed approach, harmonic sampling is not directly applied on the RF signal but on the binary signal resulting delivered by the comparator. Provided that non-destructive sampling condition is respected, the resulting signal is a low-frequency digital signal that still contains relevant information on the phase and amplitude of the original RF signal; it is the role of the post-processing algorithm to retrieve this information. In our case,we have chosen to capture the 2.4GHz RF signal with an ATE sampling frequency of 1.21GHz, which produces an aliased digital signal at 19.2MHz with a resolution of about 63 samples per period.

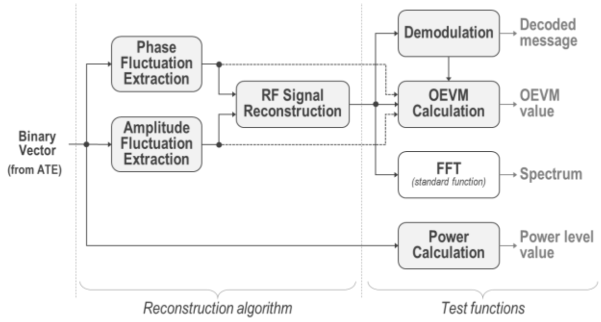

Fig. 2. Block diagram of the post-processing algorithm

Regarding the post-processing algorithm, its block diagram is illustrated in Fig.2. The first steps are to extract information on phase and amplitude fluctuations of the RF signal from the binary vector captured by the ATE. From these two extractions, a reconstructed software version of the original RF signal is computed. Additional processing functions are then applied on this reconstructed signal in order to demodulate it and perform power, spectrum and EVM

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calculations. For details on the implemented functions, refer to [6] for phase extraction and demodulation, [7] for amplitude extraction, signal reconstruction, power and spectrum calculation, and [8] for EVM calculation.

III. Results

Two measurements campaigns were conducted on a ZigBee transceiver developed and fabricated by NXP Semiconductors. Measurements were carried out on an Advantest 93k ATE equipped with both RF and digital channels (PortScale RF & PS 1600). The post-processing algorithm, initially developed in the Matlab® environment, has been optimized and ported to C to be executed directly within the ATE software. Some modifications have also been made to optimize its execution time. Details on the optimization of the algorithm are available in [9].

For the first measurement campaign, 928 pieces previously evaluated during their production with a standard test using PortScale RF channels were taken back. These pieces were then subjected to a second evaluation with the proposed solution using standard PS 1600 digital channels. The main weaknesses of this first campaign are: (i) the second evaluation took place in another geographic site with a different interface board and at a different time, which might entail a variation in the measured circuit performances. (ii) no pre-characterization of the digital channel had been performed and (iii) OEVM evaluation were performed only under the nominal configuration. To palliate these weaknesses, a second campaign was carried out on 600 pieces. In the new setup, both RF and digital captures were realized in the same environment and without any interruption of the device operation, a pre-characterization of the digital channel was realized and used to correct the digital measurements, and OEVM evaluation were performed on a larger dynamic range by playing on some internal configuration registers (SPSF2 is the nominal configuration with a very low OEVM around 0.5%, SPSF1 and SPSF0 are degraded configurations with OEVM around 0.7% and 1.3% respectively).

Results are summarized in Table I to III, which report the statistics of the error between the digital measurement and the conventional RF measurement for power level, spectrum and OEVM evaluation.

TABLE I. Statistics of power level digital measurement error

	+10dBm	**0dBm**	**-10dBm**
Mean Error	-0.00dB	-0.01dB	0.23dB
Rms Error	0.03dB	0.05dB	0.39dB

TABLE II. Statistics of spectrum digital measurement error

	Main lobe (around 3dBm)	**Lower 3rd lobe** (around -40dBm)	**Upper 3rd lobe** (around -40dBm)
Mean Error	0.01dB	-0.01dB	-0.00dB
Rms Error	0.42dB	0.63dB	0.67dB

TABLE III. Statistics of OEVM digital measurement error

	SPSF2 *Nominal Setting*	**SPSF1** *Degraded Setting 1*	**SPSF0** *Degraded Setting 2*
Mean Error	0.05%	0.02%	-0.00%
Rms Error	0.10%	0.12%	0.17%

Regarding power level measurements, good measurement accuracy is observed with a mean error close to zero. The rms error is also very low for +10dBm and 0dBm levels, and only slightly increases for -10dBm level but remains below 5%. This can be explained by the low amplitude of the signal received by the digital channel (few millivolts) due to the strong attenuation introduced by the ad-hoc wiring of the test setup, which makes the measurement more sensitive to noise. An adapted design of the interface board between the DUT and the tester should permit to diminish this error.

Regarding spectrum measurements, good measurement accuracy is also observed with a mean error close to zero and a rms error that remains contained below 0.7dB. This is a very satisfactory result considering that the symbol sequences used for the RF measurement are not identical to those used for the digital measurement, which introduces a variation in the lobe power.

Finally regarding OEVM measurements, here again good measurement accuracy is observed, with a mean error close to zero. The standard deviation slightly increases as the OEVM value decreases but remains very well contained, i.e. even in case of an OEVM value as low as 0.5%, the standard deviation does not exceed 0.17%.

Globally, these results show that the measurement error observed with the digital solution is in the same order of magnitude than the conventional RF measurement uncertainty, for the three tests specified by IEEE Std 802.15.4. These results therefore fully validate the developed solution.

IV. Conclusion

In this paper, a solution for low-cost digital production test of ZigBee transmitters in industrial environment has been presented. The fundamental approach is to perform undersampled 1-bit acquisition of the RF signal with a standard digital ATE channel and apply a dedicated post-processing algorithm on the captured signal in order to retrieve the original RF signal characteristics and implement the different tests specified by IEEE Std 802.15.4. The solution has been validated on a ZigBee transmitter with measurements performed on an industrial ATE using both the conventional RF test technique and the digital one. Results of two measurement campaigns on more than 1.5 thousand of devices have demonstrated the effectiveness of the proposed digital solution to perform accurate power level, power spectrum and EVM measurements.

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