Low-cost testing of a 2.4GHz ZigBee transmitter using standard digital ATE

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***Abstract*— In this abstract, we introduce an original technique that permits to perform the full RF test of a 2.4 GHz ZigBee transmitter using a standard digital channel instead of an expensive RF channel. The solution is based on a 1-bit under-sampled acquisition of the RF signal associated with a dedicated post-processing algorithm. Results obtained through laboratory experiments as well as an implementation in a real industrial test floor demonstrate that the technique permits to implement the standard tests required to evaluate the product quality, i.e. EVM measurement, spectral mask test and power measurement.**

***Keywords*— RF test, ZigBee, OQPSK, 1-bit acquisition, digital signal processing, digital ATE, EVM measurement**

I. Introduction

Testing cost of RF devices dedicated to the Internet Of Things is a major issue for semiconductor manufacturers. Classical techniques in use today consist in the use of Automatic Test Equipment (ATE) equipped with RF channels. However, such channels are very expensive and lead to very high-test cost. Moreover, these resources are generally available in small number reducing the multi-site efficiency. On the counterpart, digital channels are cheap and available in large number on a standard ATE. In this context, an interesting approach is to develop solutions that target RF testing using digital resources, In [1], a reference RF transceiver accompanied by an FPGA that interfaces the transceiver with a digital ATE is used to handle test signal generation/reception; in [2] a digital ATE system has been developed to test RF devices with QAM modulation.

Our objective is to develop a solution that relies on the use of a standard digital ATE channel in order to perform the test of ZigBee transmitters. Such circuits deliver a 2.4 GHz signal modulated with OQPSK format and half-sine pulse shaping. The conventional practice for testing these circuits is to use an ATE equipped with expensive RF channels. Such channels include high-performance hardware resources that perform down conversion and digitization the RF signal; digital signal processing procedures can then be applied on the digitized data stream to extract various signal characteristics and verify whether they comply with the product specifications. In case of a ZigBee product, the three main tests that are applied are power measurement, spectral mask test and EVM (Error Vector Magnitude) measurement.

II. Proposed Test Solution

The proposed test solution relies on the acquisition of the RF signal generated by the Device Under Test (DUT) with a standard digital channel as illustrated in Fig.1. A dedicated processing algorithm is then applied to this binary capture that permits to reconstruct an image of the original RF signal. Finally, classical digital signal processing procedures are applied on the reconstructed RF signal to implement the standard tests required to evaluate the product quality.

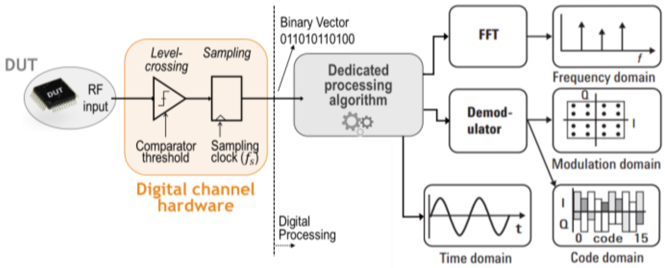

Fig.1. Proposed test solution based on the use of a digital tester channel

Basically, the hardware resources of a digital tester channel consist of a comparator and a latch; they therefore implement 1-bit conversion and sampling of the RF signal. The choice of the sampling frequency is an essential parameter of the test solution. Typically, standard digital channels have a maximum sampling rate of 1.6 GS/S, which means that under-sampling is mandatory. To comply with this constraint, the RF-modulated signal is sampled at a frequency closed to a submultiple *n* of the carrier frequency f_c; the comparator threshold is set to approximately 70% of the expected RF signal amplitude. The resulting signal is a square-wave signal with a central beat frequency at $f_b = |nf_s - f_c|$, but that still contains relevant information concerning phase and amplitude variations of the original RF modulated signal. It is the role of the post-processing algorithm that has been developed to retrieve this information and reconstruct the RF modulated signal.

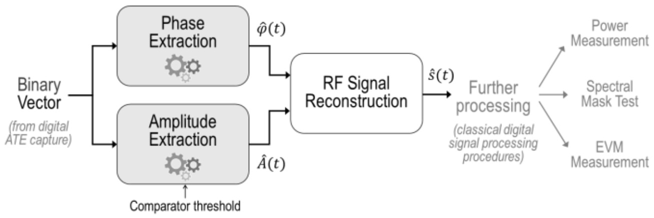

Fig.2. Simplified block diagram of the post-processing algorithm

More precisely, the algorithm involves three main blocks as illustrated in Fig.2. The first two blocks operate in parallel, one being dedicated to phase fluctuation extraction and the other to amplitude fluctuation extraction. These two blocks involve a succession of carefully designed operations that include filtering, interpolation, Hilbert transform, unwrapping, duty cycle to amplitude conversion (more details on the different operations can be found in [3]). The third block is dedicated to the reconstruction of the RF modulated signal, which is performed by adding the estimated amplitude fluctuation $\hat{A}(t)$ and the estimated phase fluctuation $\hat{\varphi}(t)$ to an ideal RF sine-wave at carrier frequency: $\hat{s}(t) = \hat{A}(t) \cdot \sin(2\pi f_c t \pm \hat{\varphi}(t))$.

III. VALIDATION

A. Laboratory experiments

The experimental setup shown in Fig.3 has been developed to perform a first validation of the strategy. A Universal Software Radio Peripheral (USRP) is used to emulate the DUT. Using USRP, we have the possibility to include controlled imperfections in the RF signal. The RF signal is split using a resistive power divider to ensure impedance matching. The first output of the power divider is connected to an oscilloscope. The second output is connected to a latched comparator that emulate the digital channel of an ATE. The binary signal (output of the comparator) is then also captured by the oscilloscope. For this validation, we use a carrier frequency $f_c = 2.48\,GHz$ and a sampling frequency f_s=1.25GS/s. The oscilloscope performs the acquisition at 5GS/s to satisfy the Nyquist rate for the RF signal; decimation by a factor 4 is performed on the second channel to reproduce under-sampled acquisition at 1.25GS/s.

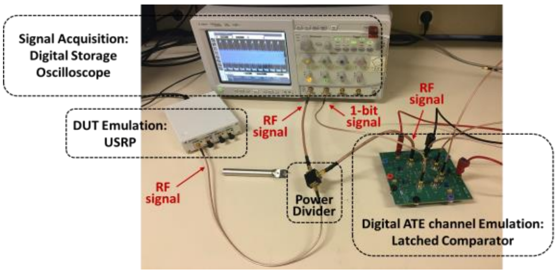

Fig.3. Experimental setup for hardware measurements

A number of experiments have been performed using this setup, varying the RF signal amplitude level or injecting phase noise and IQ imbalances to decrease the signal quality. For each experiment, both the RF signal and the decimated binary signal acquired by the oscilloscope have been transferred to a PC and processed in the Matlab environment. The dedicated post-processing algorithm has been applied on the binary signal to obtain a reconstructed RF signal; classical processing procedures have then been applied on both the original RF signal and the reconstructed one to extract their characteristics.

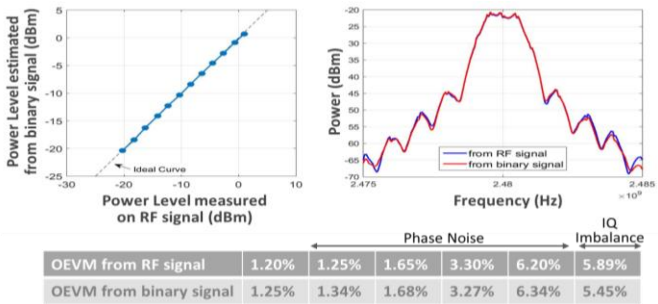

Fig.4. Comparison between measurements on the original RF signal and estimations from the binary signal

Illustrative results are given in Fig.4. Regarding power measurements, a very good match is observed between the power level estimated from the binary signal and one measured on the RF signal over a broad range of power levels, with a maximum error that remains below 0.3dBm. An excellent agreement is also observed between the spectrum computed directly on the RF signal and the one computed on the reconstructed RF signal after processing of the binary signal. Finally, regarding EVM measurements, the error between the standard RF measurement and the binary one is inferior to 0.1% in case of low EVM values, and then slightly increases in case of degraded signal quality but remains lower than 0.5%.

B. Industrial validation

To corroborate results obtained with the laboratory setup, an experiment has been done in a real industrial environment. In particular, 928 devices of an NXP ZigBee transmitter previously measured on a conventional test floor (ATE with RF option) were taken apart and evaluated again with the proposed digital solution. Acquisition has been performed by a PS1600 digital channel of V93k ATE and all the processing procedures (implemented in C) have been integrated in the test flow. For each device, the error between the original RF measurement and the evaluation from the digital capture has then been computed. Results are summarized in Table I for the three measured performances, i.e. power level (measurement at -10dBm, 0dBm and +10dBm), 3rd lobe power (spectral mask test) and EVM measurement.

TABLE I. ERROR BETWEEN THE ORIGINAL RF MEASUREMENT AND EVALUATION FROM THE DIGITAL CAPTURE

	Mean Error	Std Deviation	Max Error
Power level	0.0dBm	0.8dBm	2.6dBm
3rd lobe power	0.0dBm	0.6dBm	2.2dBm
OEVM value *	0.2%	0.1%	0.5%

* *OEVM: Offset EVM*

These results show that the proposed solution permits accurate estimation of the RF signal characteristics. Regarding power measurements, we have a mean error of 0dBm which indicates that the error distribution is perfectly centered, a low standard deviation below 1dBm and a maximum error of only few dBm, which is in the same range as conventional RF measurement uncertainty in industrial condition. For EVM measurements, we have a very small overestimation using the binary capture with a mean error of 0.2%, but again a low standard deviation of 0.1% and a low maximum error of 0.5% which is comparable to the conventional RF measurement uncertainty. These results are extremely positive taking into account that the digital test has been performed in a different environment than the initial RF test and with an interface board not optimized for the digital acquisition.

IV. CONCLUSION

In this work, we have developed a low-cost solution that permits the implementation of all the measurements necessary to a production test of ZigBee transmitters using only a standard digital ATE. The technique is based on under-sampled 1-bit acquisition of the RF modulated signal and a dedicated post-processing algorithm that performs RF signal reconstruction from the binary capture; additional procedures are then applied to the reconstructed signal to implement the standard tests required for product quality assessment. Results evaluated through laboratory experiments and on industrial test floor demonstrate the ability of the technique to perform power measurements, spectral mask test and EVM measurements.

ACKNOWLEDGMENT

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