Accuracy of System-Level Figures of Merit for Wireless Communications Products

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Abstract: This paper examines the most important measurands used in wireless communications systems at the air interface. Unlike traditional measurands though, wireless communication measurands are not traceable and tend to be considerably more complex than more conventional measurands such as current or frequency. They are more a function of probability and more dependent on the test conditions applied. Error Vector Magnitude, (EVM) is an example of a key measurand important to wireless operators, infrastructure and mobile manufacturers. The effects of the degradation of EVM performance are though not intuitive. Complementary cumulative distribution function (CCDF) is an example of where test conditions are crucial to establish a meaningful figure of merit. This paper shows how standards bodies have attempted to overcome the problem of lack of traceability by specifying exhaustive test conditions. This allows wireless operators to select equipment with a higher level of confidence thereby protecting their capacity, revenue and profitability.

1. Introduction

In some quarters, there remains a perception that modern wireless communication systems do not have the requirement for accurate measurements because being digital they are based on ones and zeros. At the air interface though, signal degradation needs to be quantified. This is achieved by selecting appropriate measurands i.e. particular quantities subject to measurement. In wireless communications, there are many measurand examples. In common with all measurands, the importance of measurement accuracy and measurement uncertainty has been recognized for many years. A detailed guide with international consensus was achieved by the International Organisation for Standardization (ISO). In 1993, they published the *Guide to the expression of uncertainty in measurement*, [1] or GUM. There are national organizations such as UKAS [2] and NIST [3] who assist companies to develop practices, methodologies and management systems to achieve accreditations for their measurements. One of the effects of the fast moving wireless communications industry is that the measurements needed to achieve maximal capacity, optimal quality of service and maximum profits are highly complex with little or no traceability. The National Physical Laboratory, (NPL) is aware of the problem. It is working with international measurement authorities, industry and academia to attempt to resolve the situation. In the mean time, wireless operators need to be able to compare infrastructure and handset vendors specifications so that their selection is appropriate for their network and business planning needs.

2. Key Measurands and definitions

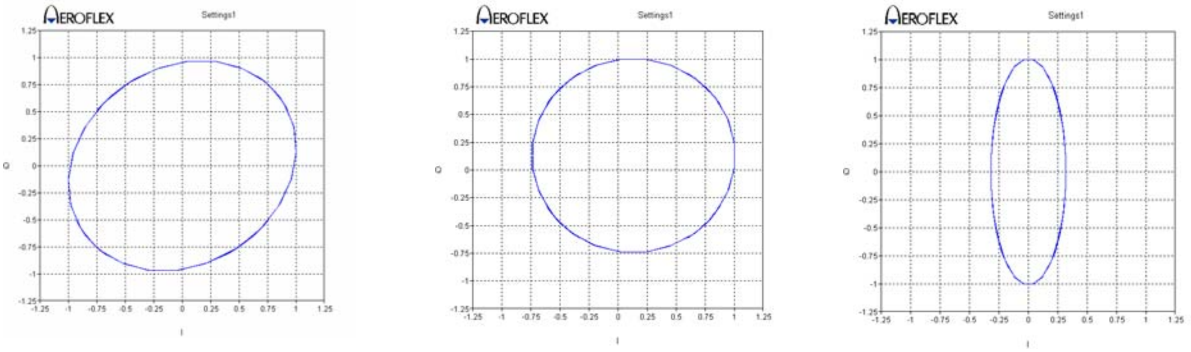
When considering measurands it is worth referring to some of the GUM definitions, as they remain true for the more complex wireless communication measurands.

Accuracy of a measurement is the closeness of the agreement between the results of a measurement and a conventional true value of the measurand.

Accuracy of Measuring Equipment is the quantity which characterizes the ability of a measuring instrument to give indications approximating to the true value of the quantity measured.

Clearly the importance of closeness of the agreement between results and the ability of the measuring instruments are key to being able to establish the level of confidence in measurements. In practical terms, this allows us to compare one product with another and establish a figure of merit. The measurands appropriate to digital wireless communications systems are more complex than more conventional and well-understood measurands such as current of frequency. The main differences are that the measurements are more a function of probability and even more dependent on the test conditions applied. The key measurands include Error Vector Magnitude, (EVM), Adjacent Channel Leakage Ratio, (ACLR), Complementary Cumulative Distribution Function (CCDF), crest factor, power level, occupied bandwidth, spurii. It is recognised that Average Revenue Per User, (ARPU), handset battery life are also very important but beyond the scope of this paper. Most measurands are related to the constraints and limitations of the hardware within the system.

In order to illustrate the importance of these measurands the effects of a degraded EVM performance is shown. IQ trajectories can be affected by skew, I Carrier leak, Q Carrier leak and gain imbalance.



a) b) c)

Figure 1: IQ trajectories with a) skew b) carrier leak c) gain imbalance

It is not always intuitive how they affect the system performance making diagnosis of product design or manufacturing process difficult and expensive. It can be seen using an analyser the effect on the flatness of the burst and the phase noise. Plots of the degraded burst flatness and phase-noise are shown in figures 2 and 3.

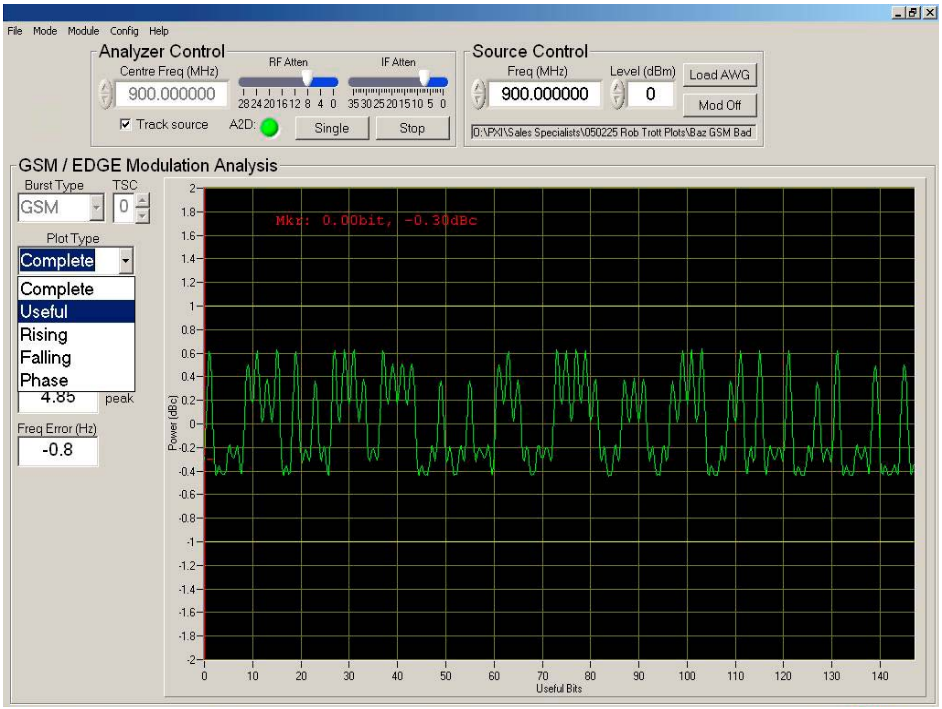


Figure 2: The flatness of the useful region of a GSM burst degraded by 1degree skew, 5% carrier leak and 0.5dB gain imbalance.

Clearly measurands such as EVM are important as they can affect the performance of the system in a number of ways. As with all measurements we don't know the "true value" and an uncertainty is effectively a figure of merit for the reported measurement. In order to gain an improved measurement uncertainty, it is necessary to optimise and define the test conditions and methodology. This is no different from well-understood practices when measurands such as current. To reduce uncertainty of measurement we would consider improved measurement equipment accuracy and optimising test methodology. Complex wireless measurands should be treated no differently. Technology improvements and fierce competition have driven costs to commodity product levels. Wireless operators can demand interoperability between their vendors.

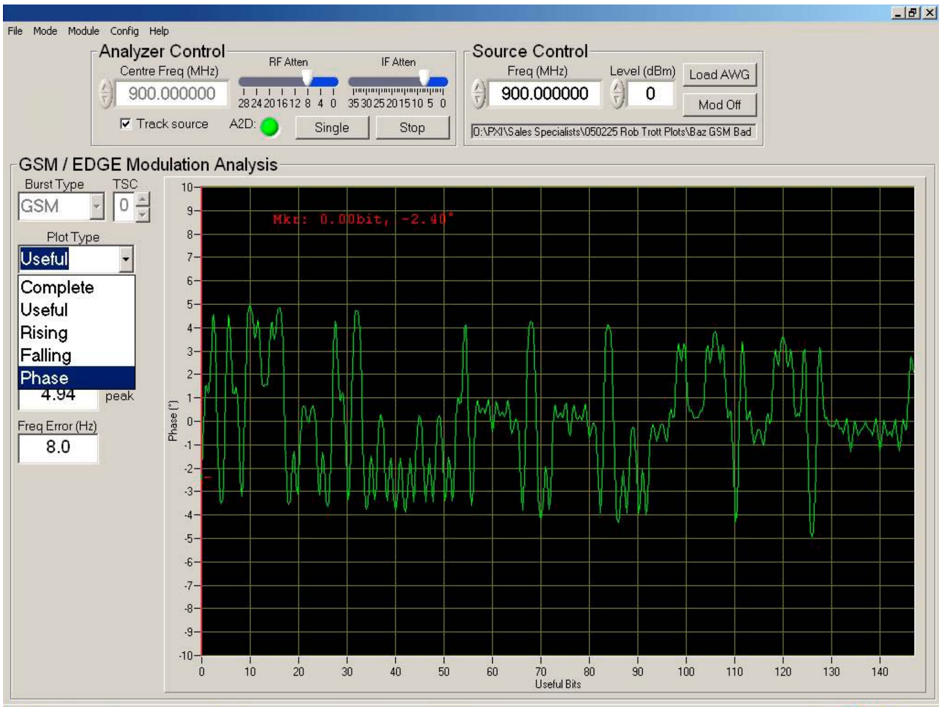


Figure 3: The phase noise performance of a GSM burst degraded by a 1degee skew, 5% carrier leak and 0.5dB gain imbalance.

In order to achieve interoperability, there is a need for accurate test equipment and standards test methodologies so that wireless operators can compare figures of merit when buying infrastructure like base-stations. The standardized test methodologies and test conditions are even more necessary as there are more criteria that can influence and effect the measurements. To illustrate the problem, wireless operators needing to buy base stations employing WCDMA multi-carrier power amplifiers need to compare the specifications using the same the test conditions. Non-constant envelope signals are particularly challenging to amplifier design and the performance varies under different test conditions. Performance can vary with time and is affected by statistical and spectral characteristics, code selection, timing offset, clipping and forward error correction. Clearly we need to know the complete test case for each figure of merit. Complementary cumulative distribution Function CCDF specifies the probability of exceeding power thresholds. A plot is shown in figure 4.

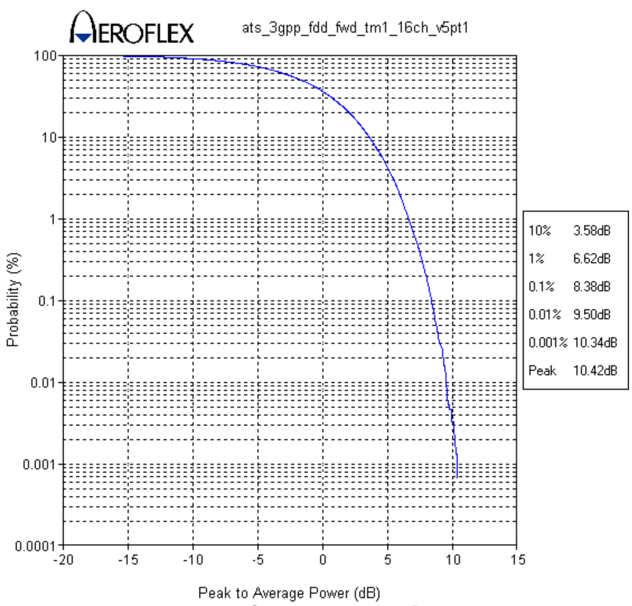


Figure 4: CCDF curve of a 3GPP signal.

3. Standards Bodies

Standards bodies with representatives from wireless operators, infrastructure equipment vendors, test equipment vendors partially address the problem. The 3rd Generation Partnership Project (3GPP) [4] is an example of a standards body developing test models and test cases. The test models are chosen to represent real life scenarios. For example, one of the test models in 3GPP TS 25.141 represents a Node B (base-station's) transmitter when many calls are in progress, to mobiles at different distances from the Node B. This kind of signal has a high peak-to-average power ratio causing stress to the Node B's power amplifier. It is therefore used in several test cases. The test models use unambiguous configurations for the signal under test. They may specify code channels to be used and their relative magnitudes. Different test models may have different CCDF's representing different real life scenarios. A test case will specify one or more measurands. For example Adjacent Channel Leakage Ratio (ACLR). 3GPP specifies that base-stations should achieve a minimum of –45dBc. As Test-equipment vendors are members of standards bodies they have been able to develop software tools that can in conjunction with the equipment quickly and easily generate complex waveform files. For instance signal generators can generate 3GPP/WCDMA Test Model 1 64 channels with ACLR<-70dBc @5MHz offset. The highly accurate test equipment reduces measurement uncertainty. The tools can be also used, not purely for design validation but produce simulations at various stages of product design verification by producing customised implementations of modulation standards.

4. Conclusions

Measurands for wireless communication systems, although more complex than well understood measurands such as current and frequency, need to be treated in the same way as measurands. The problem of the lack of traceability of complex wireless communications measurands has been partially overcome by the rigorous application of test methodology agreed by standards bodies. The need for highly accurate test equipment is vital but now with a means to easily generate specified test conditions. Test equipment suppliers working with standards bodies and infrastructure equipment vendors enable wireless operators to select equipment accurately specified thereby reducing risk to capacity, revenue and quality of service.

5. Further Research

One of the questions remaining is whether wireless communications actually need to be traceable to the same extent as more conventional measurands. This issue will be considered in further papers. This subject is a small part of a thesis on the verification and validation of wireless products. Previous research has determined that product geometry has condensed into chip-sets and modules instead of numerous discrete components. Chip-set manufacturing corporations are already finding the test costs severely impacting profitability. The intention is to innovate new RF structural test techniques using Design For Test (DFT) facilities enabled by new technologies.

6. References

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