APD Measurements for Characterization and Evaluation of Radio Interference in Steel Mill

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Abstract— **The use of wireless applications in industrial environments is rapidly increasing. Examples are remote-controlled cranes, doors and robots. The electromagnetic interference in such environments can cause severe problems and therefore has to be characterized to avoid accidents and disturbances in the production processes. In this paper it is shown how the measurements of the Amplitude Probability Distribution (APD) can be combined with conventional electric field measurements for such characterization in a steel production plant.**

Key words: APD, wireless communications, electromagnetic interference, bit error probability, industrial applications.

I. INTRODUCTION

A rapidly growing market is wireless communications for machine-to-machine communications in industries, nuclear plants and hospitals. Examples are communication between robots and some type of controller or navigation systems for autonomous vehicles in large factory halls. Remote controlled cranes and door openers are other examples. Industrial and hospital environments usually exhibit significantly higher levels of radiated electromagnetic interference than for instance an office environment. This electromagnetic interference arise from different electronic systems within processes and maintenance systems. Present commercial wireless communication technologies are not optimized to cope with these kinds of interference environments. A number of serious accidents where electromagnetic interference has been the primary cause are reported in the literature and confirms the need for research about these demanding environments. Users also confirm a variety of problems with their wireless systems in industrial environments. In some applications, radio remote controlled systems are used in applications that are critical for the production process. Therefore, the need for non-disruptive communications with high reliability is high. Thus, interference problems must be handled when they occur. Furthermore in the planning process of new wireless applications in an industrial environment, great care must be taken to choose the right frequency bands and communication technologies so that the risk for interference problems is minimized. In order to cope with interference problems, the electromagnetic interference has to be characterized. A classical method of characterization is to measure electric field strength versus frequency for the frequency region of interest. The advantage of this method is that an overview of the interference level is obtained. For more detailed interference analysis of the impact on wireless systems, more specific information is required.

One method with this purpose is to measure the Amplitude Probability Distribution (APD) of the envelope of the output from the IF-filter in a measurement receiver. Given the APD for a certain radio frequency band, detailed analysis of the interference impact in terms of bit error probability (BEP) can be done. This method has so far not been used to characterize the interference in industrial environments. In this paper, the measurement method as well as results from such characterization in a steel-production plant is presented. It is shown how the APD may be used even in heavily disturbed environments to analyze the interference impact on wireless applications.

The paper is organized as follows. In section II, the basic APD properties are briefly reviewed. In section III, the measurement method used for characterization of radio interference in industrial environments is presented. In section IV, some typical measurement results from a steel production plant is shown together with a presentation of the analysis methodology of the impact from this interference on wireless communications. It is shown how APD measurements combined with electric field measurements gives information that can be used to evaluate the performance of wireless communications in industrial applications.

II. APD

A common approach to analyze the interference impact on digital radio systems is to measure the interference power and then assume that the interference signal can be modeled as Additive White Gaussian Noise (AWGN). One big drawback with such approach is that the wave form, not only the power, of an interfering signal can significantly affect the performance of a disturbed system. The error in the estimated BEP can be in the order of several magnitudes [1]. This is a well-known result within intersystem-interference research. For this reason, information about the waveform of the interference signal must be obtained. One method for this is to measure the APD of the interference signal.

The APD is defined as the part of time the measured envelope of an interfering signal exceeds a certain level. We assume that the measured signal is ergodic and that the measurement time of the APD is long enough to capture the statistical properties of the signal. The relation between the $APD_R(r)$ and the probability density function of the envelope R of a signal is,

$$\mathrm{APD}_R(r) = 1 - F_R(r) \qquad (1)$$

and

$$f_R(r) = \frac{d}{dr} F_R(r) = -\frac{d}{dr} \mathrm{APD}_R(r) \quad , \qquad (2)$$

where $F_R(r)$ and $f_R(r)$ denote the cumulative distribution function (cdf) and probability density function (pdf), respectively. The APD can be estimated by a spectrum analyzer, where the signal is first converted to an intermediate frequency and band limited by a resolution bandwidth filter. The signal can then be compressed by a log amplifier, after which the envelope is extracted by an envelope detector.

The practical advantage with the APD is that the interference impact in terms of bit error probability (BEP) for a system exposed to the interference in the APD can easily be determined directly from the APD. For binary modulation the maximum BEP is the APD at the point where the exposed system has its received signal level, see Fig. 1.

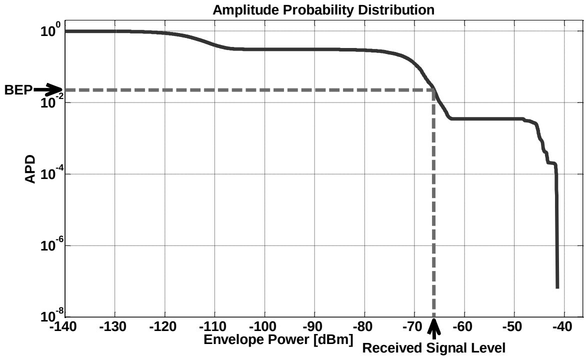

Fig. 1 The relation between APD and BEP.

For example, it is shown that [2]

$$P_{\mathrm{b,max}} = APD_R(\sqrt{E_b}) \ , \qquad (3)$$

where $\sqrt{E_{\mathrm{b}}}$ denotes the bit energy for a coherent BPSK receiver and $P_{\mathrm{b,max}}$ denotes the maximum BEP. For other digital modulation schemes, similar expressions exist [2].

III. MEASUREMENT SETUP

The APD measurement setup is shown in Fig. 2. The measured signal is passed through an A/D converter after which the data samples are collected and the APD is determined. The resolution bandwidth (RBW) for the spectrum analyzer should ideally be the same as the receiver bandwidth of the wireless systems to be analyzed.

The sampling rate f_s for the A/D conversion must satisfy the Nyquist criterion. It is also important to collect as many samples so that the APD is stationary (ideally the APD should be ergodic but in practical applications stationary in the weak sense is a convenient criterion).

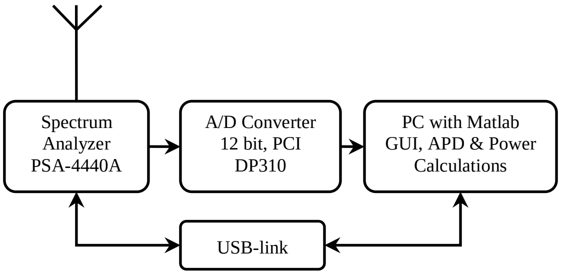

Fig. 2 Measurement setup for APD measurement.

The spectrum analyzer used was the Agilent PSA-E4440A and the peak detector was used to detect the envelope of the IF signal. One 12 bit A/D converter (Agilent DP310) was used. As a complement to the APD measurements, conventional electric field measurements were done according to CISPR 16 both with peak and average detectors. The antenna used (CBL6112A) is a wideband antenna complying with CISPR emission measurements.

IV. MEASUREMENT RESULTS

Electric field strength versus frequency was measured for 200 MHz – 2.5 GHz at selected locations in the steel production plant. Typical results are shown in Fig. 3-Fig. 4. APD were measured for selected frequencies. Typical results are shown in Fig. 5-Fig. 7. Except from different radio transmitters, broad-band interference can be seen. This interference arises from automatic robots moving around carrying steel.

Several radio systems for remote-controlled equipment are located in the frequency region 400-500 MHz. One ISM-band is located at 433 MHz (ISM = Industrial Scientific Medical). Another ISM-band is located at 868 MHz. In frequency region 200 MHz – 500 MHz the antenna used has a poorer sensitivity than for higher frequencies. However, the measured interference is far below the radio signals for remote control in this frequency region why this problem does not affect the analysis in our special case for the steel production plant.

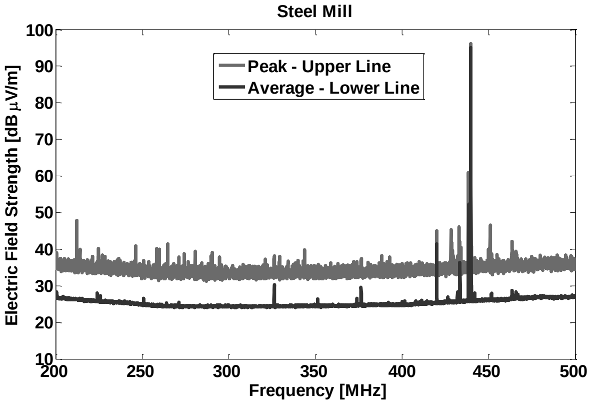

Fig. 3 Measured electric field strength in center of steel mill.

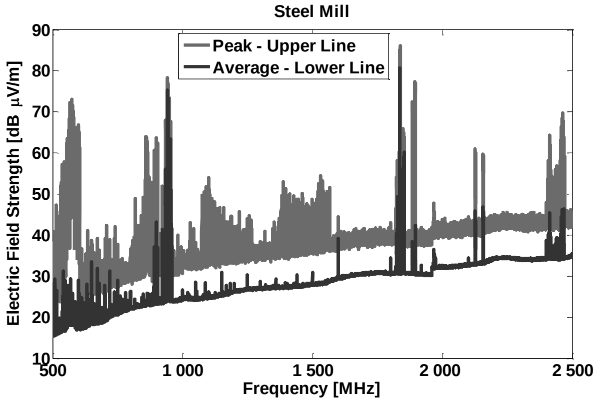

Fig. 4 Measured electric field strength in center of steel mill.

The conventional measurement of electric field strength versus frequency gives an overview of the interference level. However, since the waveform of the interference signal, not only the power, has large impact on the BEP, a combination with APD measurements gives the necessary information. In Fig. 5, the APD has the typical shape of Gaussian interference.

A reference is shown in Fig. 5 – Fig. 7 that is the noise of the spectrum analyzer in 30 kHz resolution bandwidth, assuming ideal AWGN. The displayed average noise level on the spectrum analyzer is -155dBm/Hz. The noise power for the reference signal is then calculated according to Eq. 4.

$$P_{\mathrm{AWGN\_Ref\_dBm}} = DANL + 10\cdot\log_{10}(RBW) \tag{4}$$

The APD is calculated for this reference noise and shown as a reference in the measurements. A deviation from the reference is an indication that at least one externally generated signal/interference is received. The x-axis for the APD figures is labeled as envelope power measured at the spectrum analyzer.

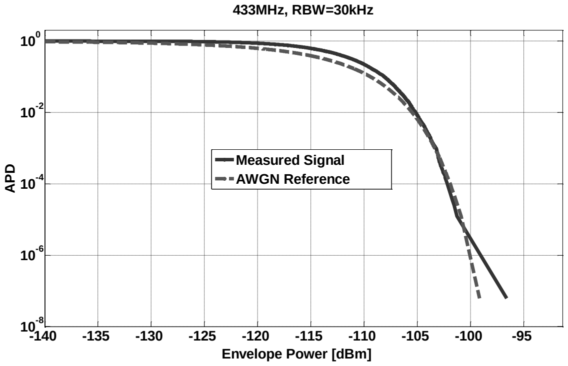

Fig. 5 Example of measured APD. Typical Gaussian shape.

Fig. 6 shows a typical APD for a modulated signal. The modulated signal introduces a terrace that shows the statistical power variation in the signal.

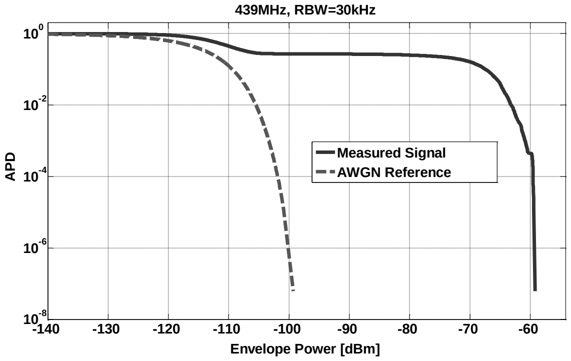

Fig. 6 Example of measured APD. Typical shape where an intentional modulated signal is the dominant interference signal.

In Fig. 7, the same modulated signal as in Fig. 6 is received. However, a pulsed signal interference with a duty cycle of $3\cdot10^{-3}$ is also measured. This interference is due to a 2-stroke transportation vehicle used within the steel mill running by and radiating interference each time the ignition system fires.

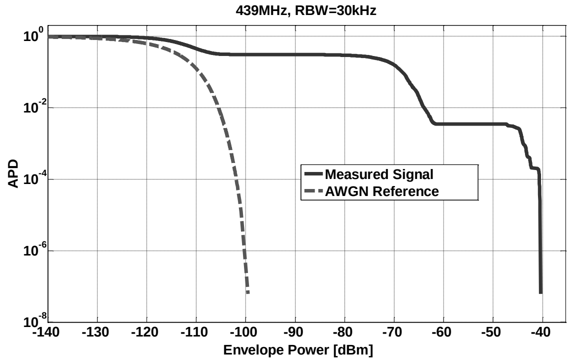

Fig. 7 Example of measured APD. Typical shape where pulsed interference with a duty cycle of $3\cdot10^{-3}$ is the dominant interference signal.

The absolute total power level can be determined from the electric field measurements. Thus, the measurement of electric field strength versus frequency gives the interference power and the APD gives the necessary information about the interference signal waveform. A more correct value of the BEP can then be determined for wireless systems exposed to the interference, see Fig. 8 for the method used.

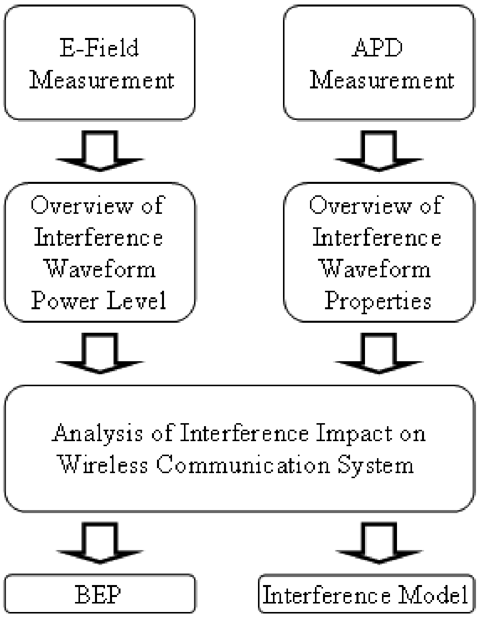

Fig. 8 Method to estimate BEP from E-field and APD measurements

It should be noted that Equation (3) gives an upper bound for the BEP. By the method in Fig. 8, a value more close to the true value can be determined.

V. CONCLUSION

We have shown how conventional measurements of electric field strength versus frequency can be combined with APD measurements to determine the information necessary for evaluation of interference impact of wireless systems in industrial applications. This approach makes it possible to distinguish between different interference waveforms so that a more correct value of the interference impact in terms of BEP can be determined compared to if only electric field measurement or APD measurement only is used.

The method has been used to characterize the interference environment in a steel production plant where the interference showed up to be dominated by interference from automatically moving robots. This interference turned out to be close to Gaussian interference by inspection of the APD. Other interference could be shown to arise from modulated signals from other radio transmitters for remote control.

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