

Fundamental limits of measurement in telecommunications: Experimental and modeling studies in a test optical network on proposal for the reform of telecommunication quantitations

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Abstract. Proposals for a review of the limits of measurement for telecommunications are made. The measures are based on adapting work from the area of chemical metrology for the field of telecommunications. Currie has introduced recommendations for defining the limits of measurement in chemical metrology and has identified three key fundamental limits of measurement. These are the critical level, the detection limit and the determination limit. Measurements on an optical system are used to illustrate the utility of these measures and discussion is given into the advantages of using these fundamental quantitations over existing methods.

1. Introduction

When describing a substance, sample or signal the most common approach is to measure the area under investigation using a quantitative approach. The questions arise as to how does a measurement approach recognize that a substance, sample or signal is detected or not? These questions of detection are fundamental in all fields of measurement.

The limits of quantification in instrumentation have been extremely controversial and has evoked much debate over decades [1, 2]. Currie [3] has introduced recommendations for defining the limits of measurement for chemical metrology instrumentation. The introduction of Currie's recommendations for defining the limits of measurement has led to the establishment of international recommendations for this field. This paper proposes the application of these methods into the field of telecommunications.

2. Evaluation of the limits of measurement in telecommunications and comparing these to other scientific fields

For many years an international effort has been undertaken by metrological scientists to establish a series of objective measurements for detection and measurement purposes. A common triple question arises when trying to quantitatively analyze a substance

1. Is the signal present?
2. What are the chances that the signal can be detected?
3. What magnitude is the signal?

Before the establishment of an accepted approach for detection limit calculation a wide range of terms, conventions and concepts that were contradictory have been used [2]. In analytical science the limits of measurement have long been a controversial [3]. Not until the introduction of Currie's landmark paper did anyone truly understand the level of confusion to the terms detection-limit, detection threshold, minimum detectable signal and detection. It was not until 1995 that recommendations were published to establish the limits of measurement for these scientific fields. Instead of talking about vague detection limits of a system three separate limiting levels were defined.

1. The critical level: The signal level above which an observed instrument response may be reliably recognized as "detected". Here the signal emerges from the background noise. A signal has been detected. The signal is greater than the noise.

2. The detection limit: The true net signal level that may be expected to lead to detection. The magnitude of the signal is 3 times the standard deviation of the noise. The 3 sigma limit is a term associated with the detection limit [4].
3. The determination limit: The signal level above which a quantitative measurement can be stated with a relative uncertainty.

These recommendations were extremely important and the aim here is to introduce Currie terminology in telecommunications for the analysis of signals.

In telecommunications a variety of detection, measurement and analysis approaches have been defined as seen in the previous section. In telecommunications the calculation that one signal is above a certain confidence level is not good enough. The idea of the detection and measurement limits is different therefore for telecommunications and Chemistry.

When applying the terminology used by Currie to telecommunications to describe the quality of signals the usefulness becomes clear. A unified scientific approach has evolved.

Critical level: If above the critical level but below the detection limit, a signal response has been detected but signal is not of high enough quality to make an accurate prediction of the signal state.

Detection limit: If the signal is between the determination level and the detection limit, the signal may be detected accurately but not with enough accuracy for the telecommunications system to receive a BER certificate.

Determination level: Finally if the signal is above the determination level. The signal is of sufficient enough quality for reliable communication to occur and to receive a BER certificate.

From Currie the three levels may be defined as;

$$L_C = k_\alpha \sigma_0 \quad (1)$$

Critical level, k = point on the x axis where there would be an error of deciding that a substance is present when it is not, The signal is present and is misinterpreted (false negative)= k_α , σ is the standard deviation of the blank signal.

$$L_D = L_C + k_\beta \sigma_0 \quad (2)$$

Detection limit. k = point on the x axis where there would be an error of deciding that a substance is not present when it is present, σ is the standard deviation of the detected signal. The signal is not present but is misinterpreted as a signal (false positive)= k_β

$$L_Q = k_Q \sigma_Q \quad (3)$$

Determination limit: k = point on the x axis where the signal is a specific level of quality. σ is the standard deviation of the detected signal.

4. Examples of practical applications in telecommunications

In this section the validity of the application of this approach is shown. A signal will fall into one a number of different categories. The critical level, detection limit and determination level.

Example 1:

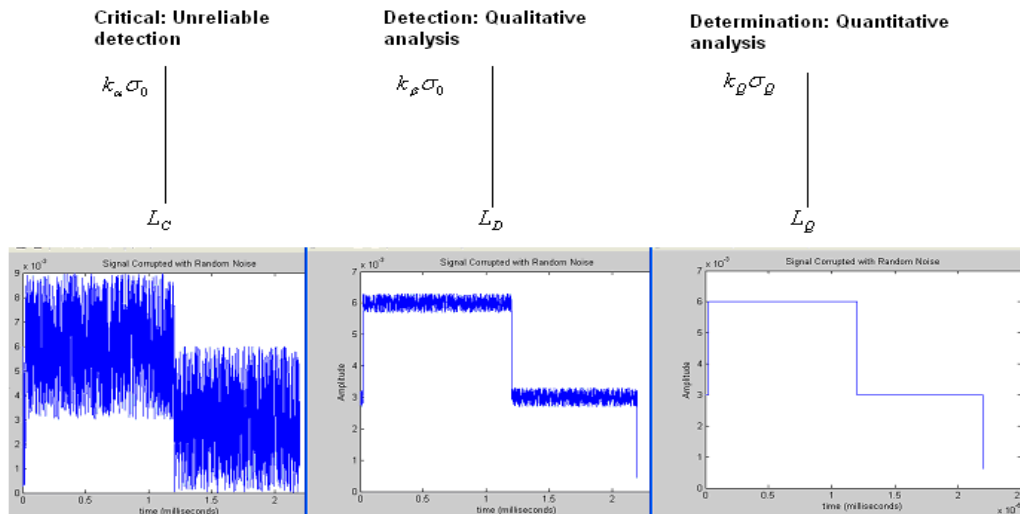


Figure 1: Simple illustration of Curries 3 levels.

In figure 1 a simple illustration of Curries 3 levels is shown. It can be seen when the signal is at the critical level as signal has been detected but it is very unreliable to measure the signal at this stage. At the detection limit the signal can be qualitative determined. At the determination level the signal is at a very high quality and it meets a particular quality of service.

It is proposed in this paper to introduce Curries three levels to telecommunications. Each technique used in the receiving side of a telecommunications system may be itself categorized as belonging to one of Curries three levels. Some of the techniques may belong to more than one field.

Example 2:

In telecommunications it is preferable to have as many signals as possible multiplexed onto the link. This is providing that the multiplexing does not affect the quality of the signals on the link. In the following 3 figures it can be seen that signals have been multiplexed together. A question arises into how many signals can be multiplexed and how close together then can be spaced before they interact with each other and cause an error.

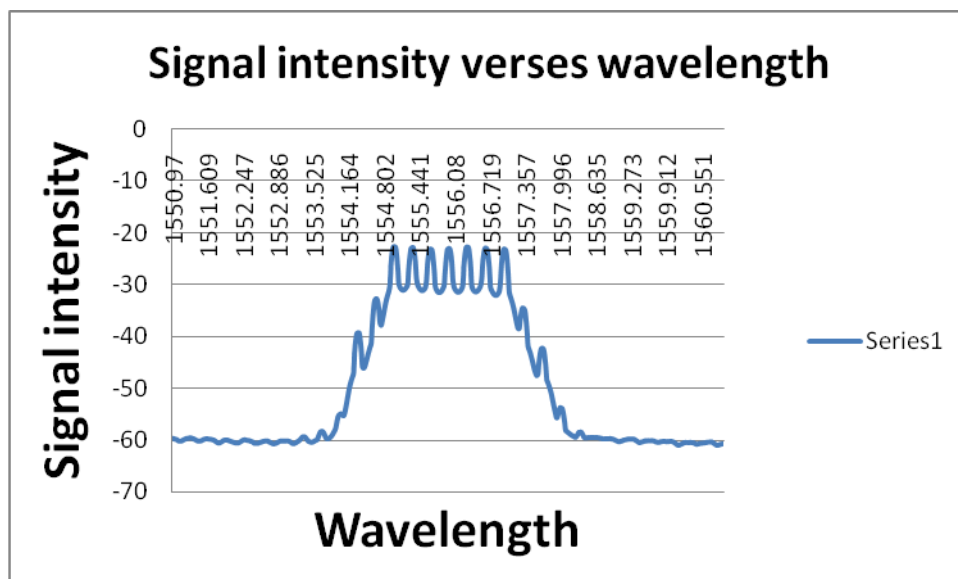


Figure 2: CWDM multiplexed signals with 7 Channels of CWDM spacing.

Techniques such as CWDM and DWDM are constantly being improved and developed. With DWDM channel spacing is less than 1000GHz. Maximum channel counts currently exceed 200. There are many limitations associated with increasing channel capacity. The higher the level of line width the greater the crosstalk with adjacent channels. The introduction of a universal language for specifying the limits of detection in this area via Curries methodology is proposed.

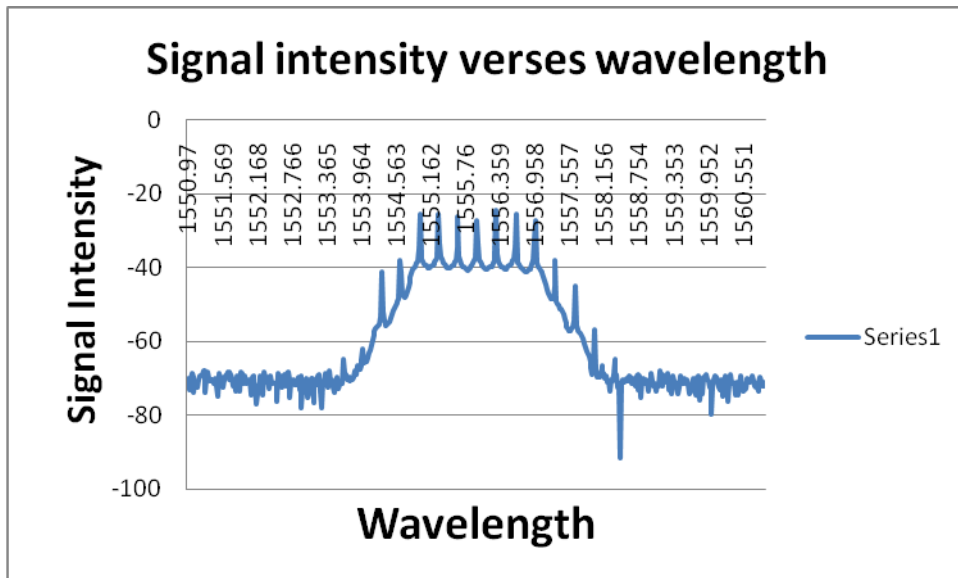


Figure 3: CWDM multiplexed signals

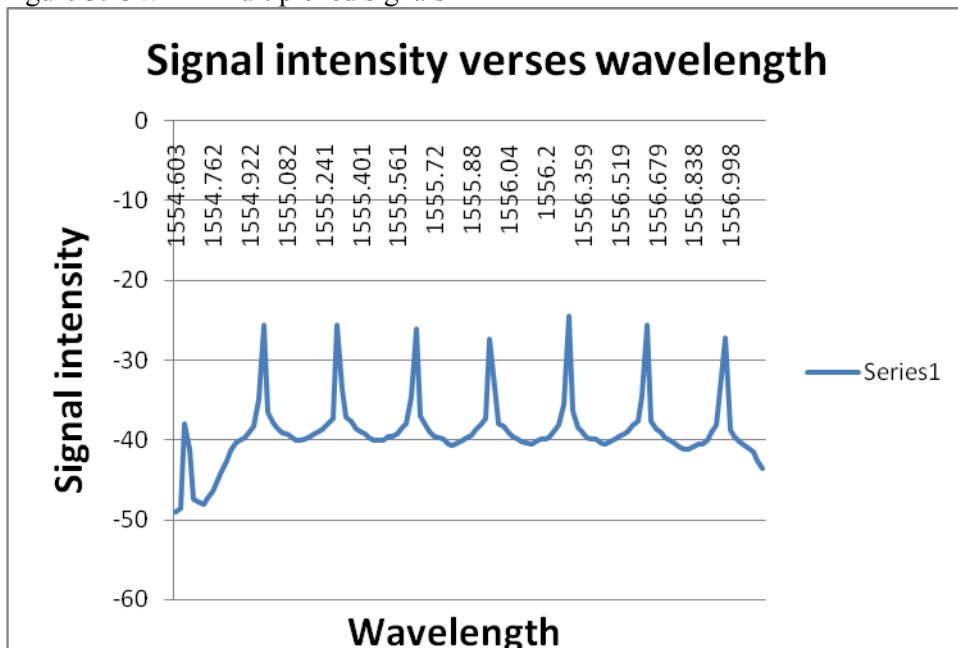


Figure 4: CWDM signals

In Figure 4 if we highlight in on the area of interest we see that the CWDM signals are spaced very close together. A question arises as to what is the maximum spacing the signals can be spaced together. Currently this is defined by the Reilleigh Limit telecommunications has been all about improving and finding new limits. To describe any improvements on this technique it would be very useful to have a standard way across all areas of science to show how the measurements have been improved. By using Curries 3 methods this can be achieved. The terminology can be reused time and time again.

5. Application of approach for telecommunications

Practical issues and implications of adopting these new structured set of quantitations in telecommunications are listed.

1. There are little practical problems associated with integrating these measurements for use in telecommunications.
2. The advantage of using this approach is that they can be used in conjunction with and are not intended to replace current methods of detection in telecommunications. Some examples of the usage of this approach: Using the eye-diagram it can be seen that the detection limit has been achieved but not the determinations level: The BER test has confirmed that the determination level has been reached.
3. There is the possibility to use this approach and integrate into the data sheets of any hardware product.
4. The advantage of using such an approach is to have a unity of terms across all scientific disciplines. Across many scientific domain terms there a wide verity of terms used to describe detection and the use of standard set of terms for telecommunications would be very useful.
 - Detection limit
 - Signal Detection Theory
 - Minimum detectable signal,
 - Detection Threshold
 - Limit of detection (LD)
 - Limit of quality of detection: LQ
 - Detection Threshold
 - Critical level
 - Determination level
 - Decision theory

6. Conclusion

Proposals for a fundamental review of the limits of measurement for telecommunications are made. The synthesis of this paper is that the current methods of detection and classification used in telecommunications can be integrated into one of three areas of measurement. These are the critical level, the detection limit and the determination limit. Practical measurements on an optical signal are used to illustrate these measures and some discussion is then given on the advantages of using what are fundamental quantitations over those of the existing methods.

It is the conclusion of this study that there is an opportunity to group the detection techniques used in telecommunications into three distinct areas. By using one of these three terms when speaking about detection it leaves the reader with a more comprehensive understanding about what is being discussed.

There is a significant challenge to get industry to apply such an approach. This would be a difficult as each section of science has developed its own detection limit terminology.

References

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