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Spectral Measurements Improvement Technique for IEEE 802.15.4z Ultra-Wideband Devices

Grigor Tsaturyan

Institute of Information and Telecommunication Technologies and Electronics, National Polytechnic University of Armenia, Yerevan, Armenia

Email: grigor.tsaturyan99@gmail.com

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Abstract. The adoption of IEEE 802.15.4z ultra-wideband (UWB) technology is rapidly increasing due to its capabilities in delivering precise ranging, low latency, and interference-resistant communication for indoor navigation and centimeter-level distance determination applications. This growing usage has intensified the demand for accurate testing and measuring methods, which are critical for minimizing interference and ensuring reliable performance. Traditionally, spectral measurements have been conducted using a single signal analyzer, where the noise introduced by the analyzer itself can limit the accuracy of the results. In this article, a novel approach for spectral measurements of 802.15.4z UWB waveforms is proposed, utilizing two synchronized signal analyzers combined with a cross-correlation technique. By cross correlating the received signals from both analyzers, the impact of noise is effectively mitigated, leading to a reduction in the noise of the measurement system. This approach enhances the precision of spectral measurements, ensuring that the spectral characteristics of the UWB waveform are accurately captured. A comparison of this method with traditional single-analyzer techniques is presented.

Keywords: UWB technology, IEEE 802.15.4z, synchronization of signal analyzers, spectral measurements, cross correlation, vector signal transceiver

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1. Introduction

Ultra-wideband (UWB) offers outstanding time resolution and multi-path resilience compared to traditional narrow-band IoT technologies [1]. This is a short-range wireless communications standard that uses frequencies from 3.1 to 10.6 GHz. Such systems use extremely low radiated power, which should not exceed the -41.3 dBm/MHz limit set by the Federal Communications Commission [2]. Given the extremely low power level of UWB signals, ensuring their coexistence with other communication standards is crucial. UWB signals are often transmitted across a frequency spectrum that is already utilized by various systems and applications, making interference management a vital consideration for reliable performance. Therefore, accurately defining the emission levels of UWB devices through precise measurements is essential [3]. Another critical measurement for RF signals in communication systems is the adjacent channel power (ACP). Leakage power from the main channel directly impacts system capacity by causing interference with transmissions in neighboring channels. As a result, it must be carefully monitored and controlled to ensure reliable communication and maintain network performance for all users [4]. ACP measures the leakage power from main channel to the neighboring channels (Fig.1). In most cases, the focus is not only on the absolute power levels of the neighboring channels but on the relative power levels between the main channel and the adjacent channels. This relative measure is known as the Adjacent Channel Power Ratio (ACPR). The ACPR, expressed in dBc, is calculated as [5, 6]:

$$ACPR_{dBc} = \sum_{f_{start}}^{f_{stop}} P_{Main} - \sum_{f_{start}}^{f_{stop}} P_{Adj}, \quad (1)$$

where f_{start} and f_{stop} define the frequency boundaries where the channel power was measured, P_{Main} and P_{Adj} represent the total power in the main and adjacent channels, respectively.

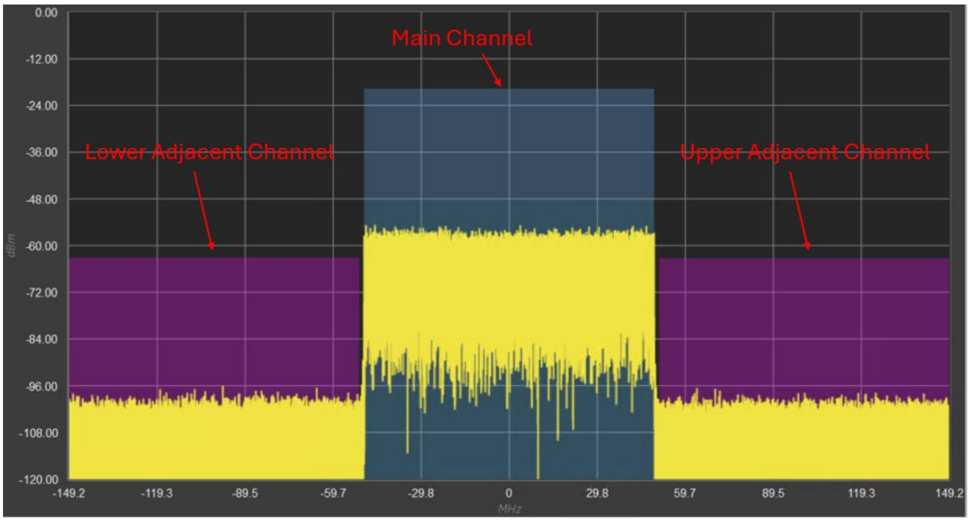


Fig. 1. Main and adjacent channels.

ACPR is a critical parameter for evaluating the spectral purity of RF signals. Maintaining a low ACPR ensures minimal interference with adjacent channels, contributing to efficient spectrum utilization and reliable system performance. Reliable spectral measurement techniques are therefore essential not only for compliance but also for optimizing the performance and coexistence of UWB technology in diverse application environments. Due to the inherently low power levels of UWB signals, noise in the measurement environment has a more pronounced impact on their spectral characteristics. The lower signal-to-noise ratio (SNR) makes UWB signals susceptible to noise interference, which can degrade the accuracy of spectral measurements [7]. As a result, additional measures are necessary to overcome these challenges and ensure that accurate and reliable measurements can be performed, even in noisy systems or environments.

This paper proposes a technique to improve spectral measurements by eliminating noise from the measurements. This is achieved by leveraging two synchronized analyzers in combination with a cross-correlation technique. The article is organized as follows: first, the principles behind the conventional single-analyzer method and the proposed two-analyzer method are introduced. Next, the experimental setup is described, including an explanation of how the two analyzers are synchronized, as synchronization is a critical requirement for enabling the cross-correlation technique. Following this, measurements are performed using both the conventional single-analyzer method and the proposed two-analyzer method. Finally, the results are compared, and the conclusions are presented.

2. Conventional single-analyzer and proposed two-analyzer methods

The primary advantage of the conventional single-analyzer method lies in its simplicity, as it requires only one signal analyzer to perform measurements. This reduces the complexity of the setup, making it straightforward to implement. The block diagram of this method is illustrated in Fig.2.

However, limitation of the single-analyzer method is that the noise introduced by the measurement system or the surrounding environment cannot be eliminated. In contrast, the proposed two-analyzer method, combined with the cross-correlation technique, effectively eliminates noise from the measurement results. By leveraging the signals from two synchronized analyzers, this method enhances the signal-to-noise ratio of the measurements. The drawback of this approach is the added complexity and cost, as an additional signal analyzer is required in the system. The block diagram of the two-analyzer method is shown in Fig.3 [8].

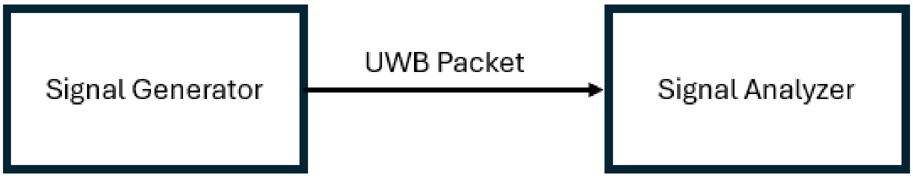


Fig. 2. Block diagram of the conventional single-analyzer method.

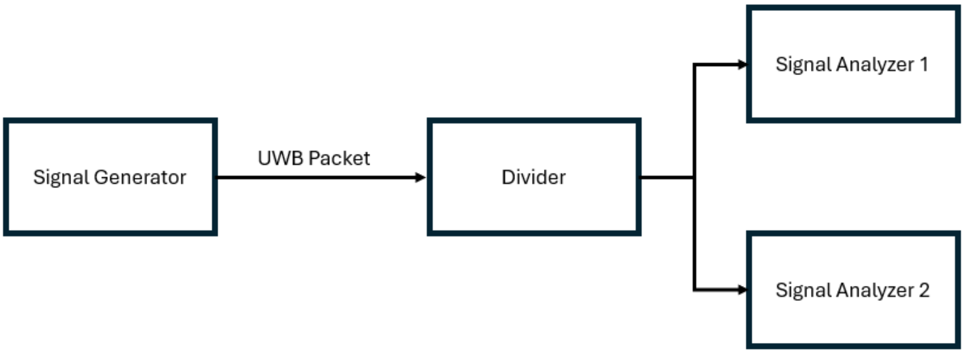


Fig. 3. Block diagram of the proposed two-analyzer method.

3. Experimental setup and results

PXIe-5831 Vector Signal Transceivers (VSTs), which operate over a frequency range of 5–21 GHz, are utilized for UWB signal generation and analysis [9]. The experimental setup includes three VSTs controlled by a PXIe-8881 controller [10], housed in an 18 slot PXI-1095 chassis [11]. For the signal generation and analysis, the following configurations were used:

- The IF0 port of the PXIe-5831 in slot 12 (VST3) was designated as the signal generator.
- During the single-analyzer method, the IF1 port of the PXIe-5831 in slot 4 (VST1) functioned as the signal analyzer.
- For the two-analyzer method, the IF1 ports of the PXIe-5831 in slots 4 (VST1) and 8 (VST2) were used as analyzers.

To achieve synchronization in the two-analyzer method, the local oscillators (LO) and clock signals of the analyzers were daisy-chained, with VST2 acting as a master and VST1 as a slave. Specifically: the LO2 OUT port of VST2 was connected to the LO2 IN port of VST1, The REF OUT port of VST2 was connected to the REF IN port of VST1. The block diagram illustrating these connections is presented in Fig.4 [12]. This daisy-chained configuration ensures that both VST1 and VST2 share the same LO and clock signals, significantly enhancing their synchronization. Combined with NI TCLK technology, this setup enables nanosecond-level synchronization between the two analyzers [13].

The synchronization level was validated by capturing a signal using the setup shown in Fig.3, where VST3 generated the signal and both VST1 and VST2 captured it based on a power trigger. In Fig.5, the blue line represents the waveform captured by VST1, while the red line corresponds to the waveform captured by VST2. The cursors indicate the timestamps of the captured waveforms, showing a time difference of $14.163055\mu s - 14.159494\mu s = 0.003561\mu s$. These results demonstrate that the analyzers achieved synchronization with a precision of approximately 4 ns.

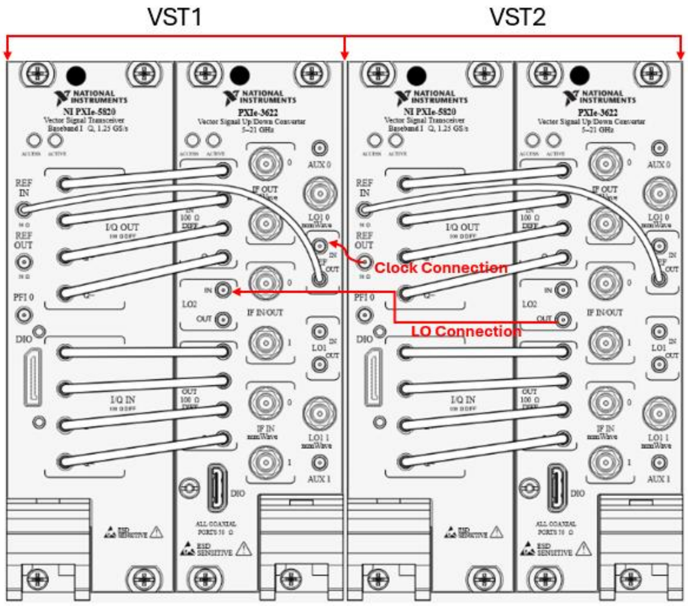


Fig. 4. LO and Clock connections between VST1 and VST2.

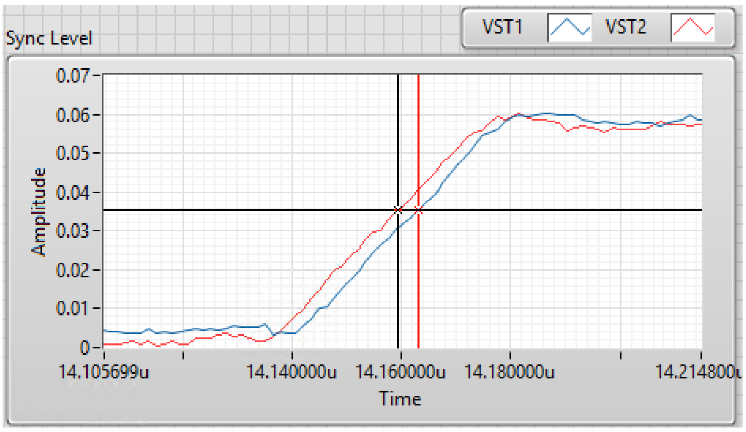
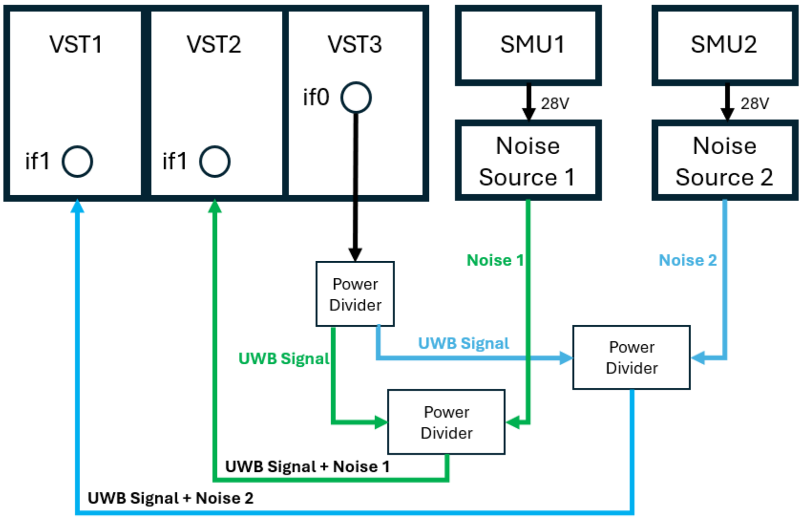


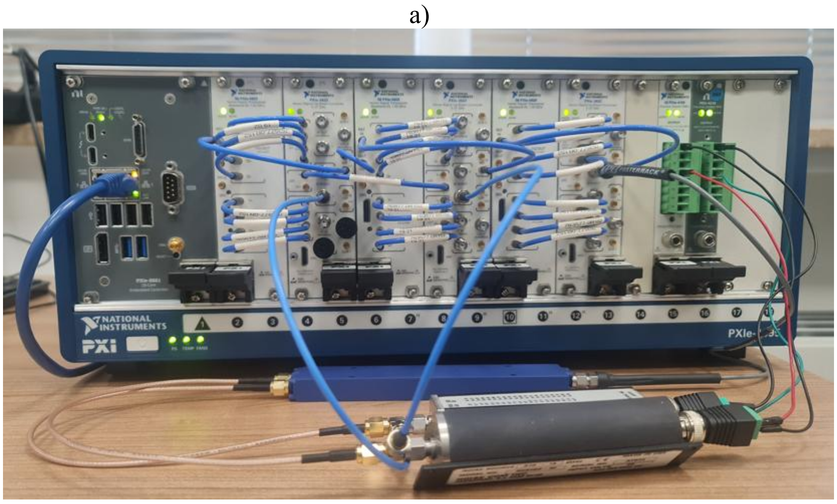
Fig. 5. Validation of synchronization level between VST1 and VST2.

To simulate measurements under noisy environments and inject additional noise into the measurement setup, two NC346D noise sources (NS) from Noisecom were used. These noise sources have an excess noise ratio (ENR) of 21.16 dB at 8 GHz and require a 28V supply voltage for operation [14]. For this purpose, two PXIe-4139 source measure unit (SMU) modules [15], located in slots 15 (SMU1) and 16 (SMU2) of the PXI chassis, were employed to supply the required voltage. The setup also includes three power dividers to facilitate signal distribution and noise injection. One power divider splits the UWB signal generated by VST3, enabling its use in the two-analyzer method. The other two power dividers introduce noise generated by the noise sources into the signal paths of the analyzers, simulating a noisy environment. The complete block diagram of the experimental setup is illustrated in Fig.6a, while an actual view of the setup is presented in Fig.6b.

To supply the required 28V for the noise sources, PXIe-4139 source measure units (SMUs) were controlled using NI InstrumentStudio software. This software enables precise voltage control and real-time monitoring of current consumption. Fig.7 illustrates the control interface, showcasing the applied 28V and the corresponding current consumption of the noise sources. Where the green lines represent the voltage and current applied by SMU1, while the orange lines correspond to those supplied by SMU2.



a)



b)

Fig. 6. a) Connection diagram of the experimental setup. b) Actual view of the experimental setup.

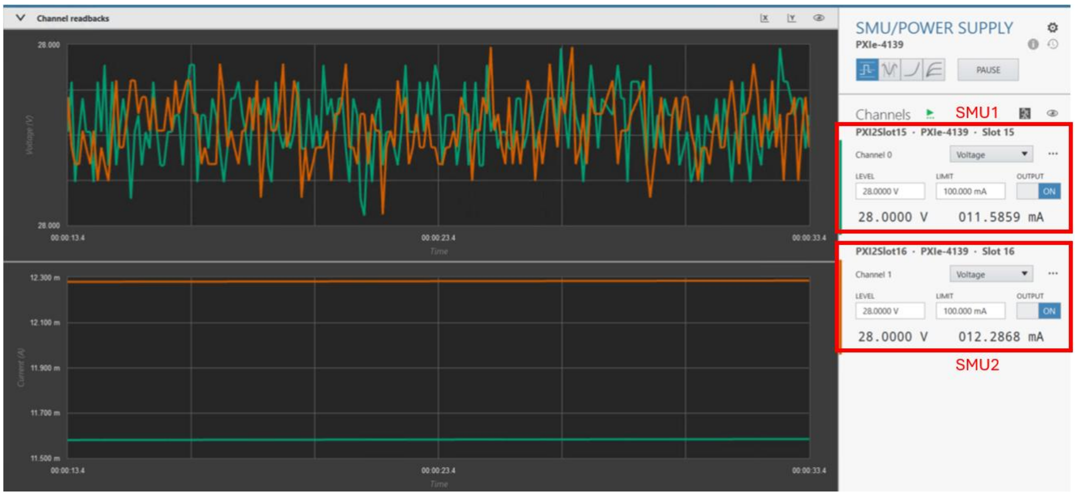


Fig. 7. Voltage and current control for noise sources using InstrumentStudio.

A UWB waveform is used for measurements with the following PHY configurations: Mean PRF = 62.4 MHz, PHR Rate = 0.85 Mb/s, Data Rate = 6.81 Mb/s, Code Index = 9, Preamble Symbol Repetitions = 64, Symbols in SFD = 8, Packet Configuration = SP2 and Channel 9 with a carrier frequency of 7987.2 MHz [16, 17]. The measurements are conducted at a temperature of +25°C. The measurement results obtained using the single-analyzer method are shown in Fig.8. The measured main channel power is -30.78 dBm, while the absolute powers of the upper and lower adjacent channels are -43.27 dBm and -43.54 dBm, respectively. This results in ACPR values of -12.48 dBm for the upper channel and -12.76 dBm for the lower channel.

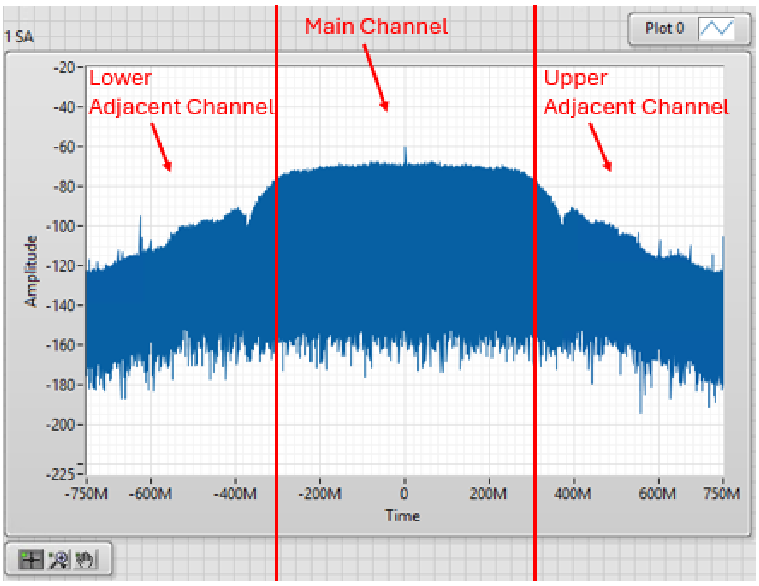


Fig. 8. Measured spectrum using the single-analyzer method.

In contrast, the measurement results obtained using the two-analyzer method are shown in Fig.9. The measured main channel power is -30.98 dBm, while the absolute powers of the upper and lower adjacent channels are -46.17 dBm and -46.51 dBm, respectively. This results in ACPR values of -15.19 dBm for the upper channel and -15.53 dBm for the lower channel. The two-analyzer method improves the ACPR values by more than 2.7 dB compared to the single-analyzer method.

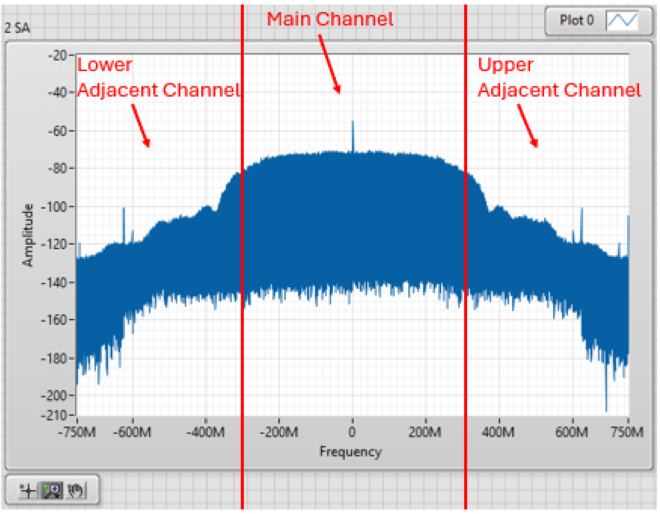


Fig. 9. Measured spectrum using the two-analyzer method.

4. Conclusions

This article presents a technique for improving spectral measurements of IEEE 802.15.4z UWB waveforms, leveraging two synchronized signal analyzers combined with a cross-correlation method. By addressing the limitations of the conventional single-analyzer approach, the proposed method effectively eliminates noise from the measurement environment. The experimental setup utilized three VSTs: one as a signal generator and two as analyzers for both single and two analyzer measurement methods. Synchronization of the two analyzers was achieved by sharing their local oscillator and clock signals, combined with NI TCLK technology, resulting in a synchronization level of 4 ns. Noise sources were also used to simulate a noisy environment. Spectral measurements conducted with the single-analyzer and two-analyzer methods were compared. The results demonstrate that the two-analyzer method improves ACPR measurements by more than 2.7 dB.

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