**Ms. No. Sensors-86249-2025** **Authors’ Reply to Reviewers’ Comments**

Analysis and Experimental Validation of SSTDR for Simultaneous Distributed Diagnosis of Wire Networks Sensor Journal.

Dear Editor and Reviewers,

We would like to thank you very much for your valuable comments and the care and time you took in reviewing this manuscript. We have made substantial revisions to the manuscript, guided by your comments, and we believe this has made it a much better paper. Thank you very much. Please find the red-lined manuscript indicating the changes made. Also, we have highlighted the changes in response to your comments below.

Thank you again. We appreciate your expertise and comments.

Mouad Addad, Ali Djebbari, Evan Benoit and Cynthia Furse

**Editor’s Comments:**

Based on the enclosed set of reviews this manuscript is not acceptable for publication in its current form, but may be acceptable after being thoroughly reworked. If you choose to resubmit, please send the reworked manuscript as soon as possible. The sooner we receive the resubmission, the better the likelihood that we can utilize the same editor and reviewers.

Thank you for your review. We believe the comments have been extremely helpful in greatly improving the paper. Details are given below in blue, and our changes to the manuscript are highlighted in blue.

----------------------------------------------------------------------------------------------------------------

**Reviewer #1:**

**Reviewer #1 Comment #1:**

Dear Author,

Complex branched cable networks such as the ones found in aircrafts can indeed be installed in harsh environment, which may result in cable defects subsequently leading to critical failure. Reflectometry is therefore a good way to monitor them, and improving old techniques like TDR /distributed TDR is thus always welcome and this makes your motivation really clear.

When I read your paper, it gave me an impression of "déjà vu" and I quickly found out why: you submitted a very similar manuscript (An Enhanced Method for the Distributed Diagnosis of WireNetworks, M. Addad & al..) in 2022.

But your work is now far more complete than it was 2 years ago because you added a whole new experimental validation section, which is greatly appreciated.

**Response to Reviewer #1, Comment #1:** Indeed, this work was initially submitted for review in 2022. Since then, we have taken the time to thoroughly validate our results , both experimentally and through simulation. We believe these additions significantly strengthen the contribution of our study.

Thank you very much for taking the time to review our work and for your valuable feedback.

**Reviewer #1 Comment #2:**

I found answers to most of questions I had at the time, except these 3 points which still remain:

- eq. (3): P is missing (upper bound of the sum)

- eq. (7): it should be s'\_{i,m} instead of s\_{i,m}

- eq. (14): it should be \delta\_{l-l\_p} instead of \delta\_{l-p}

**Response to Reviewer #1 Comment #2:** Thank you for bringing this to our attention. We have corrected these errors in the revised version of the paper.

**Reviewer #1 Comment #3:**

On the downside, I still think you should have cited [1] (I would like to point out I am not one ofthe authors), because it has been available for more than 15 years and already provides answers to most of the issues your method was designed to address.Your main contribution was to replace M/Gold Sequence by ZCZ, but the rest is quite similar.

[1] Distributed Reflectometry-based Diagnosis for Complex Wired Networks, N. Ravot & al.(2007)

Best regards,

**Response to Reviewer #1 Comment #3:** Thank you for this recommendation. We have added this reference, along with several other papers that have addressed algorithms for distributed sensing. We added the following to the introduction:

Many algorithms have been developed for network evaluation with reflectometry including the Greedy algorithm [5], iterative calculations [3], [6], reverse image searching [7], removing the pulses from nodes [8], selective averaging [2], wavelet transforms [9], [10], support vector machines [11], sensor fusion [12], genetic algorithm [13], [14], residual voltage inversion [15], time reversal [16], and more.

The algorithms described above require reflection and transmission data, typically from multiple points in the network. This can be accomplished either sequentially or simultaneously. Sequential testing can prevent interference between sensors, but can take a lot of time. Also, not all parts of the system are tested at once, and intermittent faults can be missed during this time. For continual testing and monitoring, which we will focus on, each sensor should test continually and simultaneously. For simultaneous testing, signals need to be chosen, so that they do not interfere with each other.

Each type of reflectometry uses a different test signal [1]. Time domain reflectometry (TDR) uses a stepped or pulsed incident signal, frequency domain reflectometry (FDR, used in vector network analyzers) uses multiple single-frequency sine waves or a chirp of sine waves of different frequencies, chaos TDR uses injected noise signals, and noise domain reflectometry (NDR) uses existing noise and signals in the system as a passive test system. These techniques are not suitable for testing multiple channels simultaneously, as they would interfere with each other. Testing multiple channels simultaneously requires multiple orthogonal signals. This can be accomplished with spectral time domain reflectometry (STDR) and spread spectrum time domain reflectometry (SSTDR).

And, as you correctly note:

In this paper, we focus on enabling simultaneous distributed sensing and diagnosis of branched wire networks using S/SSTDR [17] with zero-correlation zone codes (ZCZ). The advantage of these codes is that they do not interfere with each other over a specific zone (in time or space), which can greatly improve testing accuracy.

We appreciate your insightful comments, which have contributed to improving the paper.

----------------------------------------------------------------------------------------------------------------

**Reviewer #2:**

Time Domain Reflectometry (SSTDR). By evaluating the pseudo-noise zero correlation zone, it enables simultaneous distributed testing. The work is particularly interesting in the context of simultaneous distributed testing. However, I recommend the following revisions before the paper can be considered for publication:

**Reviewer #2 Comment #1:**

In the abstract, please include performance metrics (e.g., maximum length) to help readers evaluate the work more easily.

**Response to Reviewer #2 Comment #1:** Adding quantitative performance metrics is a very good suggestion. Because of the detail of explaining what the metrics are, we have added them within the text rather than the abstract. Details are included below:

A performance metric based on the merit factor was proposed in [19] to evaluate the effectiveness of different sequences. This metric is a ratio of the autocorrelation peak (representing the desired signal) and the cross-correlation sidelobes (representing the interference). It was shown in [18] that ZCZ sequences are promising candidates for simultaneous and distributed diagnosis due to their favorable correlation properties.

In addition to the previously mentioned metric based on the merit factor, we have also introduced a second performance metric in Section IV.3.A to further quantify the impact of interference on distributed measurements. We added a normalized interference error metric, which measures how the merit factor (theoretical) affects experimental performance in the presence of multiple interfering sequences:

The normalized interference error, illustrated in Fig. 9, is defined as the average difference between measurements with 0 and 15 interferers across the zero correlation zone range 0–64 m, normalized by the magnitude of the peak response at point A. For *m*-sequences, Gold codes (or sequences), and ZCZ sequences, the normalized interference error values are 0.125, 0.2, and 0.006, respectively. Similar trends are observed for SSTDR measurements in Fig. 10, where *m*- and Gold sequences exhibit normalized interference errors of 0.051 and 0.08, respectively, while ZCZ sequences show significantly lower error of 0.003.

These additions provide a more comprehensive quantitative evaluation of the system's performance under simultaneous testing conditions.

**Reviewer #2 Comment #2:**

In Section 2, Equation (6) introduces a cross-correlation function that is used to derive Equation (3) and eliminate noise signals. Please provide a detailed explanation of the reasoning behind this process.

**Response to Reviewer #2 Comment #2:** Thank you for your question. We have added detail on the interference and noise terms in equation (6) and (12):

The magnitude of the correlation in (4) depends on the length of the signals and how well correlated they are, as we will show in Fig. 2. By substituting (3) in (4), we obtain the correlation of the complete received signal

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  | + | (6) |

The first term is self-correlation of the incident signal of interest, and the second term is correlation of its reflections. Both of these signals are desired for evaluation of the network. The third term is interference from other sensors simultaneously testing on the same network, and the fourth term is correlation with the noise and other signals on the line. The last two terms are not desirable, and we should minimize them by choosing signals with low cross-correlation.

**Reviewer #2 Comment #3:**

Ensure that all figures include units on the y-axis.

**Response to Reviewer #2 Comment #3:** This is a good point. There are several different ways we could define the magnitudes on the y-axes of these figures. Correlation itself does not have a unit, and neither does the reflection coefficient (because it is a ratio of reflected and incident signals). As you have noted, this is important to clarify, however.

We have added the following after (4) when the correlation is first defined:

The magnitude of the correlation in (4) depends on the length of the signals and how well correlated they are. This is called the correlation amplitude we show in Fig. 2. We will use this correlation to evaluate more complicated systems as well.

We have also renormalized Figs. 4-10 to represent reflection rather than correlation. This will allow the user to evaluate the standard reflection coefficient equations when looking at the reflection diagrams. We added this new normalization below Fig. 4 during the discussion of the magnitudes of the peaks:

The magnitude of a reflection at a T-junction between cables of equal impedance is 1/3, so we have used this value to normalize the correlation magnitude, giving the reflection magnitudes (|Reflection|) shown in Fig. 4 and all remaining figures in this paper.

**Reviewer #2 Comment #4:**

The paper employs a test signal amplitude of 62.5 mV. Please discuss whether using different amplitudes would affect the testing results. Additionally, determine whether the test signal is a pulse signal and provide the relevant signal details. If it is a pulse signal, specify its pulse width and explain whether the pulse width impacts the test.

**Response to Reviewer #2 Comment #4:** Thank you for these questions. We have added the following to the manuscript:

Increasing the amplitude of the test signal will raise the correlation peak amplitudes, however, the overall shape of the response remains unchanged. The test signal is a square wave modulated by a sequence, with each chip having a duration of , which corresponds to sampling distance of . The sequence is up-sampled by a factor of resulting in a sample width of corresponding to a sampling distance of . If we increased Tc, this would decrease the bandwidth of the signal, increase correlation pulse width, and decrease the overall accuracy of the test.

**Reviewer #2 Comment #5:**

In Figure 3 (experimental setup), please provide additional details regarding the signal source, sensing component, and demodulation process.

**Response to Reviewer #2 Comment #5:**

This is definitely important, thank you for your comment. We have added additional details about the signal source, and how it is measured with the scope. The highlighted sections have been added, and we also added a figure to better show the ideal and measured signals. The scope is the sensing component, and there is no demodulation done in this work. Details are expanded in Section IV.1 (blue highlighted sections have been added):

We use a Rohde & Schwarz MXO5 oscilloscope with two waveform generators, as shown in Fig. 3. The function generators in this scope output predefined waveforms at 625 Msample/s, while its arbitrary waveform generators output user-defined waveforms with rates up to 312.5 Msample/s. We generated a signal sequence using MATLAB and uploaded it to the arbitrary waveform generator. The signal was captured by using one of the input channels (8 channels) with input impedance that can be set to either 50 Ω or 1 MΩ. An example of 30 chips of a 25 MHz m-sequence signal are shown in Fig. 3. The theoretical and measured values (using a direct connection between generator and scope) are compared.

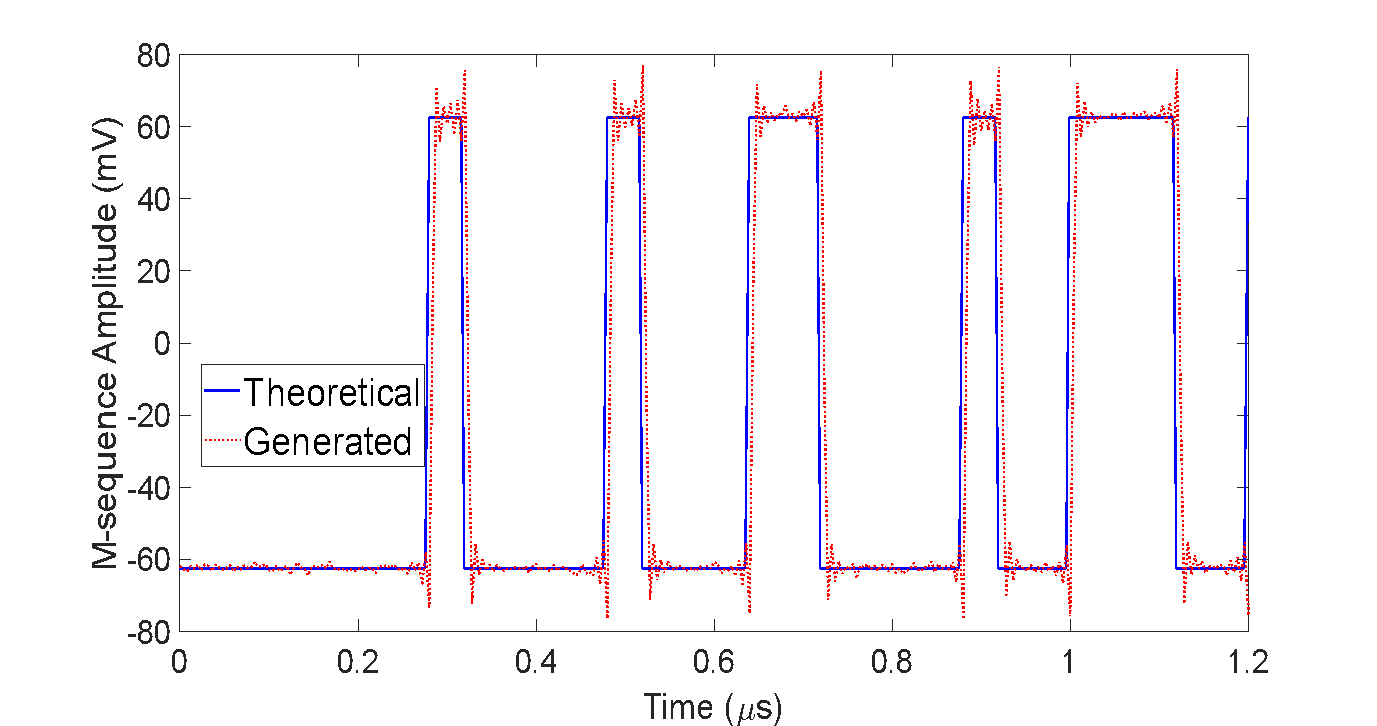


Fig 4. First 30 chips of the 25 MHz m-sequence comparing the ideal (theoretical) and measured (generated) time domain values.

Three RG-58 coaxial cables with characteristic impedance 50Ω are used to form the Y-network. Generator 1 (Gen1) is connected at A to a 30.5 m cable, which connects at B to a T-junction of 13.7 m and 31.2 m cables. The BNC T-adapter at A also connects channel 1 of the oscilloscope. The signals are generated based on sequences uploaded from MATLAB. These are either STDR or SSTDR. The STDR is a square wave modulated by a sequence (as in (1), shown in Fig. 3), and the SSTDR is a sine wave modulated by the STDR signal. The sequences are of length for *m-* and Gold sequences, and for ZCZ sequences. The chip rate is giving a chip duration of . The sequence is up-sampled by a factor of so the sample rate is *.* The highest sampling rate available for this generator is slightly above . The reflected signals come back to the scope through the T-junction at A. Then the signals are downloaded and processed (cross-correlated with the incident signal) using MATLAB.

**Reviewer #2 Comment #6:**

Include a comparative table that lists and compares the proposed method with other related work.

**Response to Reviewer #2 Comment #6:** Thank you for this comment. We considered adding this information as a table, however, we feel the following explanations addressed these comparisons more clearly. We have added additional text reviewing algorithms used to evaluate the reflectometry data:

Many algorithms have been developed for network evaluation with reflectometry including the Greedy algorithm [5], iterative calculations [3], [6], reverse image searching [7], removing the pulses from nodes [8], selective averaging [2], wavelet transforms [9], [10], support vector machines [11], sensor fusion [12], genetic algorithm [13], [14], residual voltage inversion [15], time reversal [16], and more.

We added comparison of sequential and simultaneous testing:

The algorithms described above require reflection and transmission data, typically from multiple points in the network. This can be accomplished either sequentially or simultaneously. Sequential testing can prevent interference between sensors, but can take a lot of time. Also, not all parts of the system are tested at once, and intermittent faults can be missed during this time. For continual testing and monitoring, which we will focus on, each sensor should test continually and simultaneously. For simultaneous testing, signals need to be chosen, so that they do not interfere with each other.

And we added information on different types of reflectometry that can/can’t be used for simultaneous testing:

Each type of reflectometry uses a different test signal [1]. Time domain reflectometry (TDR) uses a stepped or pulsed incident signal, frequency domain reflectometry (FDR, used in vector network analyzers) uses multiple single-frequency sine waves or a chirp of sine waves of different frequencies, chaos TDR uses injected noise signals, and noise domain reflectometry (NDR) uses existing noise and signals in the system as a passive test system. These techniques are not suitable for testing multiple channels simultaneously, as they would interfere with each other. Testing multiple channels simultaneously requires multiple orthogonal signals. This can be accomplished with spectral time domain reflectometry (STDR) and spread spectrum time domain reflectometry (SSTDR).

We conclude the introduction with:

In this paper, we focus on enabling simultaneous distributed sensing and diagnosis of branched wire networks using S/SSTDR [17] with zero-correlation zone codes (ZCZ). The advantage of these codes is that they do not interfere with each other over a specific zone (in time or space), which can greatly improve testing accuracy.

Thank you very much for your comments and suggestions. We believe these helped greatly improve the context and clarity of the paper.

----------------------------------------------------------------------------------------------------------------

**Reviewer #3:**

Comments: This paper presents and experimental validation of SSTDR for simultaneous distributed diagnosis of wire networks. However, the serous concerns needs to improve the content of the paper?

**Reviewer #3 Comment #1:**

What is the novelty of the paper? the sate of the art mechanisms are not added and discussed and the number of references is not sufficient

**Response to Reviewer #3 Comment #1:** Thank you for asking for further clarification on the novelty of this work. We have expanded the review of prior work in the introduction:

we have added additional text reviewing algorithms used to evaluate the reflectometry data:

Many algorithms have been developed for network evaluation with reflectometry including the Greedy algorithm [5], iterative calculations [3], [6], reverse image searching [7], removing the pulses from nodes [8], selective averaging [2], wavelet transforms [9], [10], support vector machines [11], sensor fusion [12], genetic algorithm [13], [14], residual voltage inversion [15], time reversal [16], and more.

We added comparison of sequential and simultaneous testing:

The algorithms described above require reflection and transmission data, typically from multiple points in the network. This can be accomplished either sequentially or simultaneously. Sequential testing can prevent interference between sensors, but can take a lot of time. Also, not all parts of the system are tested at once, and intermittent faults can be missed during this time. For continual testing and monitoring, which we will focus on, each sensor should test continually and simultaneously. For simultaneous testing, signals need to be chosen, so that they do not interfere with each other.

And we added information on different types of reflectometry that can/can’t be used for simultaneous testing:

Each type of reflectometry uses a different test signal [1]. Time domain reflectometry (TDR) uses a stepped or pulsed incident signal, frequency domain reflectometry (FDR, used in vector network analyzers) uses multiple single-frequency sine waves or a chirp of sine waves of different frequencies, chaos TDR uses injected noise signals, and noise domain reflectometry (NDR) uses existing noise and signals in the system as a passive test system. These techniques are not suitable for testing multiple channels simultaneously, as they would interfere with each other. Testing multiple channels simultaneously requires multiple orthogonal signals. This can be accomplished with spectral time domain reflectometry (STDR) and spread spectrum time domain reflectometry (SSTDR).

We conclude the introduction with:

In this paper, we focus on enabling simultaneous distributed sensing and diagnosis of branched wire networks using S/SSTDR [17], with zero-correlation codes (ZCZ). The advantage of these codes is that they do not interfere with each other over a specific zone (in time or space), which can greatly improve testing accuracy.

**Reviewer #3 Comment #2:**

Please mention the number of equations in the content of paper

**Response to Reviewer #3, Comment #2:** Thank you for this comment. We’ve gone through the paper and made sure equations are numbered and referenced throughout.

**Reviewer #3 Comment #3:**

Why do you choose PN and ZCZ codes? the motivation is not clear in paper.

**Response to Reviewer #3 Comment #3:** We have added more detail and literature review on both sequence types (why ZCZ) and reflectometry (why S/SSTDR).

In the conclusion:

The advantage of these sequences is that they have literally zero correlation over a specific zone (in time or space) which can greatly improve testing accuracy.

In Section III as follows :

Among the conventional sequences, maximal-length *m*-sequences have the smallest PACF side lobes. The disadvantage of these sequences is their PCCF peaks which increase rapidly with sequence length. Consequently, *m*-sequences are optimal for single-point diagnostic systems, but not for simultaneous distributed sensing. Large sets of sequences with relatively good PCCF such as Gold sequences can be generated from a pair of *m*-sequences called the preferred pair. Zero Correlation Zone (ZCZ) sequences have recently been introduced to the field of wire diagnostics. Their performance was evaluated in the case of simultaneous diagnosis of multiple wires in [19], distributed diagnosis of noisy wire networks in [18], and simultaneous diagnosis of shielded cable bundles in [20]. The distinctive property of ZCZ sequences is that they have a zero-correlation zone in both their PACF and PCCF, where they are ideal for testing. If the zero-correlation zone width is chosen to be large enough to encompass all of the significant reflections in the system, interference from other codes transmitting simultaneously can be eliminated.

We also added information on why we used sequences rather than other types of reflectometry in the introduction:

The algorithms described above require reflection and transmission data, typically from multiple points in the network. This can be accomplished either sequentially or simultaneously. Sequential testing can prevent interference between sensors, but can take a lot of time. Also, not all parts of the system are tested at once, and intermittent faults can be missed during this time. For continual testing and monitoring, which we will focus on, each sensor should test continually and simultaneously. In this case, of simultaneous testing, signals need to be chosen, so that they do not interfere with each other.

Each type of reflectometry uses a different test signal [1]. Time domain reflectometry (TDR) uses a stepped or pulsed incident signal, frequency domain reflectometry (FDR, used in vector network analyzers) uses multiple single-frequency sine waves or a chirp of sine waves of different frequencies, chaos TDR uses injected noise signals, and noise domain reflectometry (NDR) uses existing noise and signals in the system as a passive test system. These techniques are not suitable for testing multiple channels simultaneously, as they would interfere with each other. Testing multiple channels simultaneously requires multiple orthogonal signals. This can be accomplished with spectral time domain reflectometry (STDR) and spread spectrum time domain reflectometry (SSTDR).

**Reviewer #3 Comment #4:**

The conclusion Section needs to be summarized and the equation shou

**Response to Reviewer #3 Comment #4:** Thank you for this comment. The Conclusion Section is now summarized. Sorry…the last part of your comment was left out, and didn’t transmit to us.

----------------------------------------------------------------------------------------------------------------

Thank you again for these very helpful comments. We think they have helped us greatly improve the paper.