Chapter 7

Conclusion and Suggestions for Future Work

7.1 Conclusion

We proposed a solution to the identification of the structure and estimation of the parameters of the twisted-pair telephone local loop. The development of the identification process is divided into four phases:

1. Understanding of the identification subject,
2. Identification in the time-domain based on the time-domain reflectometry (TDR) response,
3. Application of the MODE algorithm to the problem, and
4. Identification in the frequency-domain (based on the frequency response).

The first phase addresses the first two elements of the identification process — data set and model structure — while the others are devoted to the identification method on the basis of the first phase. From a physical standpoint, the local loop is modeled as a network of several twisted-pairs. The twisted-pairs are classified into different types according to physical features such as gauges, insulation material, and operation temperature. The loop topology is depicted by a graph. The objective of the identification process is to reveal the topology of these twisted-pairs as well as to determine the length and type of the twisted-pairs used in the loop, given a single-point measurement.

The descriptive twisted-pair types are associated with a set of model parameters describing their electrical characteristics. The twisted-pair electrical characteristic model used in this work is based on the VT-TDL model. The parameters for all of the potential line types are stored in a database to be used in the identification process. The single-port measurement setup is represented as a linear time-invariant (LTI) system. Two measurement types are considered in this thesis: TDR response measurement sand frequency response measurements.

The TDR response — the measurement type used in the first identification attempt — is indicative of the structure of the local loop. The bounce diagram graphically describes the TDR response behavior as a sum of reflections returning from the loop discontinuities or loop nodes. Based on the bounce diagram, a (modular) system block diagram is derived to describe the behavior of the loop as well as the individual reflections.

The time-domain identification approach exploits the information embedded in the individual reflections of the TDR response. An iterative method is derived to sequentially model the nodes of the loop-under-identification (LUI), in the order of appearance of their corresponding reflections. Each cycle of the identification process consists of two tasks; detection of the earliest unprocessed reflection, followed by the estimation of the loop node based on that detected reflection. The reflection detection and the segment length estimation are based on the weighted cumulative sum of squared errors criterion, while the node type (how many segments are connected to the node) and the connected segments' line types are estimated based on a comparison of candidate models corresponding to all possible node structures. To improve the considered models, the length of the new segment in each model is refined by correlating its reflection with the LUI. The selection criterion used is weighted sum of squared errors. This method operates properly as long as the LUI does not contain segments short relative to their reflection pulse width. On the other hand, if two nodes are close enough that their corresponding reflections overlap each other, the processing of the overlapping reflections becomes unreliable. This undesirable behavior becomes more severe when a far-end network exists in the LUI because of the dispersive nature of the twisted-pair medium.

To resolve the difficulties associated with strongly overlapping TDR reflections, the MODE algorithm, one of the subspace methods, is introduced to decompose these TDR reflections, which are assumed to exhibit the same shape. The MODE-WRELAX algorithm — the first of the two MODE-based algorithms considered — is designed to decompose a linear combination of scaled, delayed, same shape pulses. However, the reconstructed TDR reflections based on the MODE-WRELAX estimates do not correlate well with the embedded reflections. This disagreement comes from the dispersive nature of the twisted-pair medium which causes two visually-similar pulses to be different enough to violate the MODE-WRELAX modeling assumption.

To accommodate the dispersion, another MODE-based algorithm, called the MODE-type algorithm, is considered. Although the algorithm was originally developed for the parameter estimation of undamped, damped, and explosive sinusoids, minor preprocessing of the signal allows the direct application of the MODE-type algorithm. A brief comparison of the loop subsystems frequency responses with the signal model for the MODE-type algorithm indicates that the two signal models are relatively compatible with each other. Moreover, the MODE-type experiment with the TDR response suggested that the MODE-type algorithm is capable of identifying the decomposed reflections more accurately than the MODE-WRELAX algorithm.

To incorporate the MODE-type algorithm into the loop identification process, a change of processing domain from time-domain to frequency-domain is suggested. Since both the twisted-pair model and the MODE-type algorithm are defined in the frequency-domain, it is more suitable to process the data in the frequency domain. The downside to this change is that the reflections — visually separable in the time-domain — become completely overlapping over the entire frequency range. However, the MODE-type algorithm is able to perform the decomposition properly. With the proper decomposition of the reflection frequency response, the location of the new node is reliably estimated from the phase angle of the estimate and the LUI is identified in a similarly iterative fashion as in the time-domain procedure. The difference is that the reflections are identified in the order of their strength to assure reliable parameter estimation. The change of the processing order induced an increase in the number of candidate model possibilities; a new node may be placed in between already identified nodes. The lengths of candidate model segments are optimized with the quasi-Newton method to minimize SSE — the candidate selection criterion.

The Node 1 (CO side) evaluation of the frequency-domain identification method, using 101 equally spaced frequency response measurements from 1 MHz to 2 MHz, against the set of industry test loops in the noiseless environment yields a success rate of roughly 70 %. Success is defined here as correct identification of the loop topology, correct line type selection, and segment length estimation correct to within one foot. The failure cases show that our algorithm experiences difficulties due to mainly three types of loop features:

- Long loops (> 5 km) — reflections from the far-end are too small (in computational sense),
- Complex loops (*e.g.*, bridged tap is tapped again) — two reflections occur (approximately) at the same time, resulting in the selection of the wrong candidate model, and
- Loops containing very short segments — the segment length is shorter than the resolution of the MODE-type algorithm.

7.2 Suggestions for Future Work

The above observations indicate that the frequency-domain identification method still leaves room for improvement. Further research to resolve any of the abovementioned problems may be worthwhile. To mitigate the high attenuation of the farther reflections as well as to increase the resolution of the algorithm, a different — perhaps additional — frequency range may be utilized. However, there are tradeoffs associated with selecting lower or higher frequency samples. The lower frequency region provides much stronger reflections in exchange for a lower resolution of the algorithm, and vice versa for a higher range in frequency. Concurrent processing of multiple frequency ranges and adaptive frequency range selection are two of the possible avenues towards a better solution.

To combat the difficulty with more complex loops, more extensive candidate comparisons — *e.g.*, utilizing multiple MODE-type estimates to estimate multiple nodes in one cycle — would likely aid the problem. However, this approach would cause a significant increase in the number of candidates. To further reduce the number of candidate models, the unused MODE-type estimates (*i.e.*, the magnitude part of ρ_l and a_l) could be used to estimate the node types.

Lastly, the development thus far has been strictly under the ideal condition where the model twisted-pair characteristics exactly match that of the LUI without any external disturbance. Under practical circumstances, the twisted-pair model is expected to deviate from the actual ones used in the LUI. Also, there are a number of measurement disturbances such as measurement error due to equipment, crosstalk between twisted-pairs in a cable, and A/D quantization noise. Analysis of the identification algorithm with real measurement data, or with a simulated noisy environment, is necessary. In addition, if the method is not found to be robust, robustification of the identification process needs to be addressed.