Exploiting Gating principle to circumvent the challenges of properly characterizing cables with improper terminations

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Abstract

After production, LAN cables have to be tested electrically. However, on drums, the inner end of the cable is not always easily accessible. Improper termination of the cable leads to reflections that strongly affect the measurement results and may cause the non-acceptance of the cable. The use of Fourier transforms allows mitigating this effect by gating in the time domain [1] and can help in simplifying the testing procedure for parameters such as impedance and return loss.

More precisely, gating allows mitigating the effect of "Open end" reflections that can be seen at low frequency in the impedance/return loss spectrum when measuring a non-terminated cable.

Keywords: Cables; LAN; Measurements; Gating; Fourier transform; Time domain.

1. Introduction

Measurement of LAN cables are subject to perturbations originating from the connection between the measuring Vector Network Analyzer (VNA) and the cable under test. Even if specific test fixtures are used, adequate calibration is usually difficult to achieve. This introduces spurious effects in the measured curve that often prevent from a proper cable characterization.

This is also the case when the cable far end cannot be accessed and hence is not properly terminated. Reflections at cable end, poorly attenuated at low frequencies, perturb the measurement of impedance and return loss. This creates unwanted pseudo-sinusoidal effects that superimpose on the real cable response, thus rendering analysis cumbersome [1]. Gating using frequency to time domain conversion by Fourier transform allows removing specifically the detrimental effect of cable ends in order to retrieve the sought for spectrum of the bare cable only.

2. Gating

For the gating analysis, the following parameters are used:

- f_{min}: starting frequency of the measurement
- f_{max}: end frequency of the measurement
- Δf: frequency step of the measurement
- n: number of points of the measurement
- Δt: time step in time domain
- t_{max}: maximal time of the time domain
- L: cable length
- ν: propagation speed along the cable

Starting from the measured spectrum (linear frequency scale measurement from f_{min} to f_{max} with Δf steps), the following steps are applied during the gating process [2]:

1. A harmonic grid (with frequencies defined as integer multiple of the step size Δf) is defined between $-f_{max}$ and $+f_{max}$
2. The spectrum is extrapolated to DC using a specific proprietary algorithm (please refer to description in paragraph 4.1 below).
3. The spectrum is mirrored in the negative frequencies using complex conjugate of the measurement.
4. The inverse discrete Fourier transform of the frequency spectrum gives the time domain data.
5. The time domain data is multiplied by the gating function.
6. The discrete Fourier transform converts back the time domain data to the frequency domain.
7. The final spectrum between f_{min} and f_{max} is extracted from the discrete Fourier transform.

Given that the time span after Fourier transform is given by $t_{max} \cong 1/(2^* \Delta f)$, Δf must be smaller than $\sim \nu/(4^*L)$ to be able to "see" the end of the cable in the time domain. Hence, for a given frequency span, the longer the cable is the more points is needed to "access" the cable end for gating purpose.

The gate shape is chosen as a cosine form with broad edge width to mitigate its effect on the final data.

The DC extrapolation is chosen to represent at best the behavior of the measurement at low frequency.

3. Results

The measurements are done on one pair of an L=300m long LAN cable.

fmin and fmax are chosen at 10 MHz and 251 MHz, respectively. The data is measured over 5001 points which corresponds to a Δf of 50 kHz.

For this cable, the propagation speed is measured to be 64 % of the speed of light, c. So the total length span covered by in the time domain is approximatively 960m.

3.1 Initial consideration

Open end measurement is compared to results obtained with a matching load and a short circuit at the far end as well as with Open/Short calculation which is the reference method for impedance measurement as stated in the IEC standards [4].

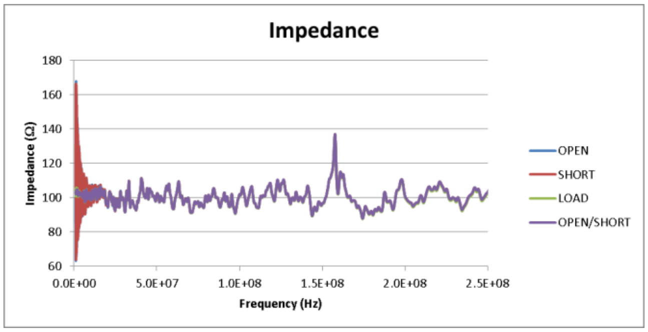

Figure 1. Impedance measurement

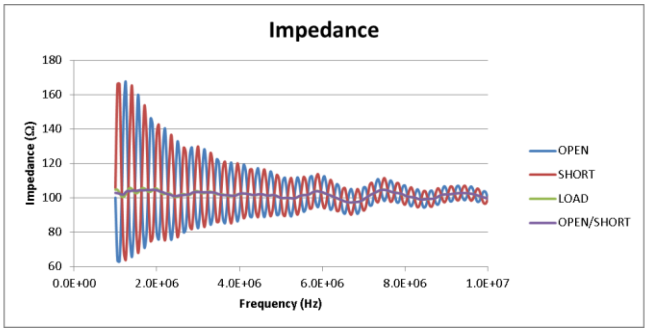

Figure 2. Close-up of the low frequency part of Impedance measurement

One can clearly see the oscillations present at low frequency in the open-ended and short-circuited measurements due to the wave reflections at far end. At higher frequencies, these reflections are strongly attenuated due to the signal absorption (insertion loss of the cable) and the open, short, load, and open/short curves overlap.

3.2 Time domain representation

As mentioned above, the measured curve is extended to DC (here chosen as a constant value equal to the lowest frequency point measurement value) and mirrored in the negative frequencies spectrum.

Time domain representation of the data clearly shows a peak at the cable corresponding length ($3.15 \cdot 10^{-6}$s). The width and the shape of the peaks (both at cable near and far ends) can be explained by the ringing due to the limited measurement frequency range (truncation) [3].

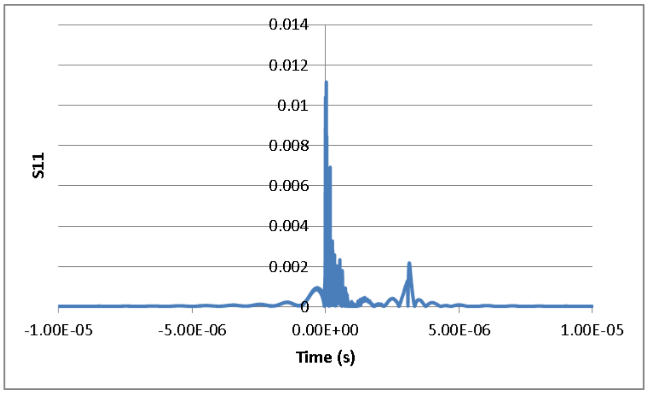

Figure 3. Time domain representation of S11

Extrapolating the spectrum at high frequencies (here by a constant interpolation up to 400MHz) helps in reducing this effect.

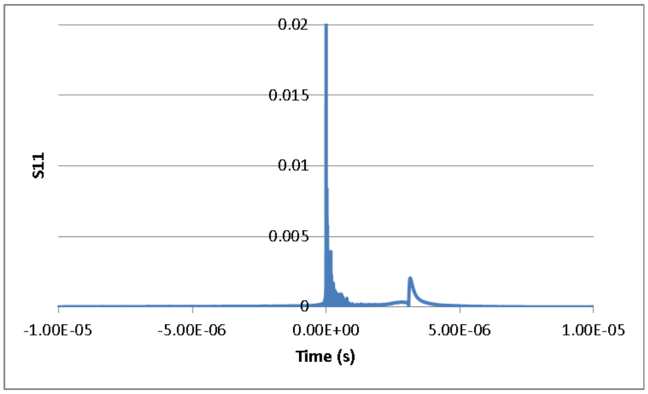

Figure 4. Time domain representation of S11 after extrapolation at higher frequencies

But this is not of direct importance here as we are not interested in time domain properties.

Note that another aspect that might bring some contribution to the peak width is the propagation time in the cable that is frequency dependent.

4. Gated curves

Due to the discrete and finite nature of the measurement, gating will introduce some spurious effects at both ends of the spectrum linked to the gate shape. This must be taken into consideration when defining the gate. Here a simple, relatively wide, cosine shaped gate has been chosen.

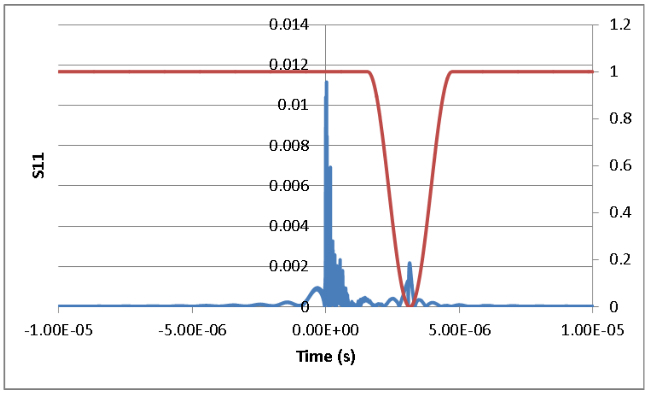

Figure 5. Gate shape

After gating, one can see that the oscillations present at low frequency, corresponding to the reflection at far end, have disappeared,

Nevertheless, a simple extrapolation of the spectrum towards DC does not allow removing completely side effects at low frequency.

Note that a similar behavior due to truncation is also present at the highest frequencies (not visible on the graph at this scale).

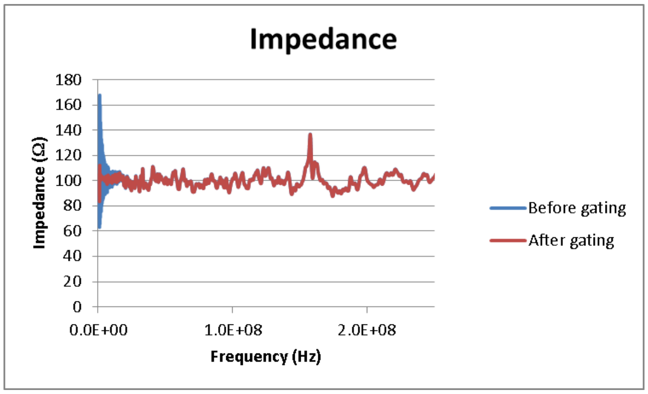

Figure 6. Impedance before and after gating

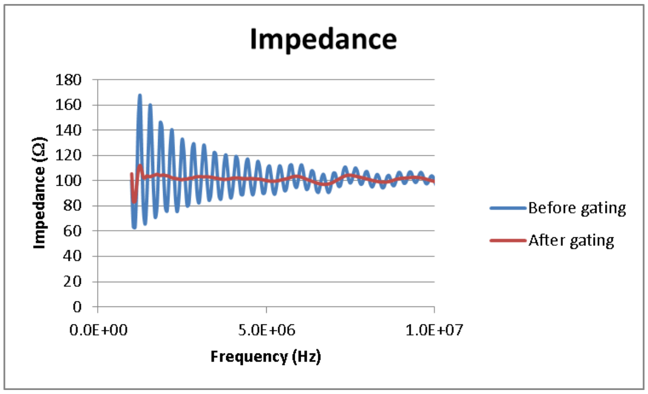

Figure 7. Close-up of the impedance before and after gating

This effect can however be mitigated in the present case of open-end measurement by some astute DC interpolation.

4.1 Specific DC extrapolation

In order to improve the extrapolation to DC, the S11 parameter, which forms a logarithmic spiral in the complex plane in our case, is further spirally extrapolated according to a proprietary algorithm.

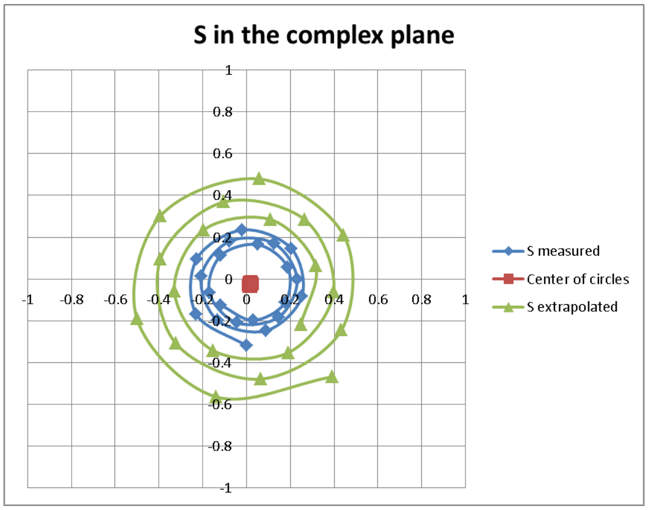

Figure 8. DC Extrapolation of S11 in the complex plane

- The center of the spiral is determined by taking a mean value of the circle's centers of 3 subsequent frequency points over 3 turns of the spiral.
- The magnitude of S is considered as exponentially growing with decreasing frequency
- The argument of S has a linear dependence with frequency

Applying the same gating process on this new curve allows shifting the spurious effects to lower frequencies, out of the measurement range, as shown on the next graphs.

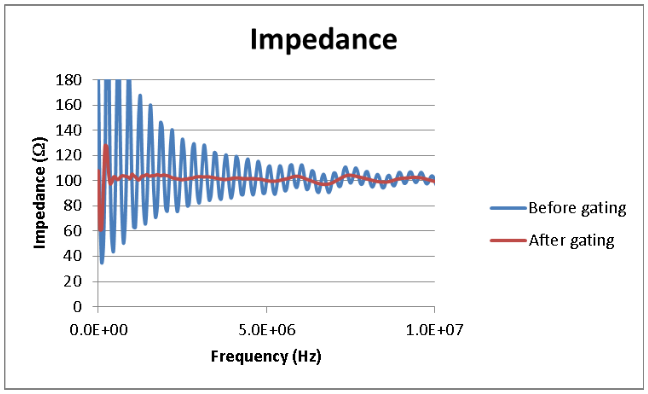

Figure 9. Close-up of the impedance of the DC spiral extrapolated curve before and after gating

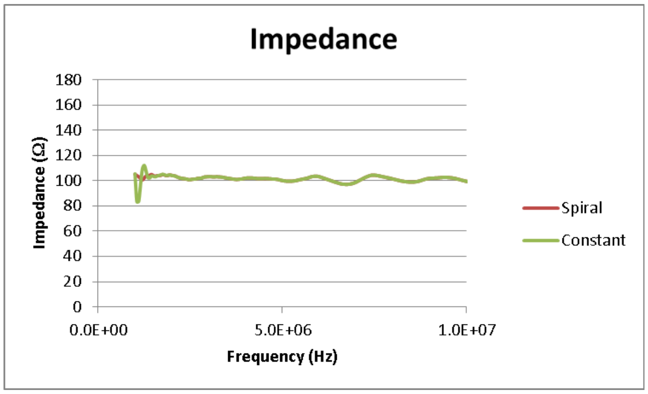

Figure 10. Comparison between constant and spiral DC extrapolation

The final curves are shown in the following graphs for comparison. The gated impedance of the open-end measurement matches quite well the reference measurement based on Open-Short method, showing the efficiency of this procedure to mitigate reflections at far end.

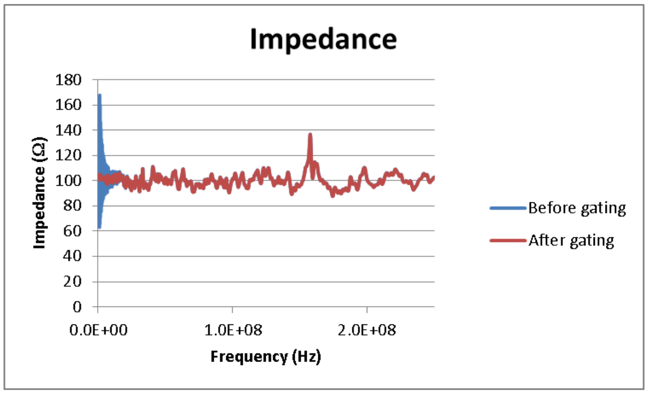

Figure 11. Comparison of Impedance curves before and after gating

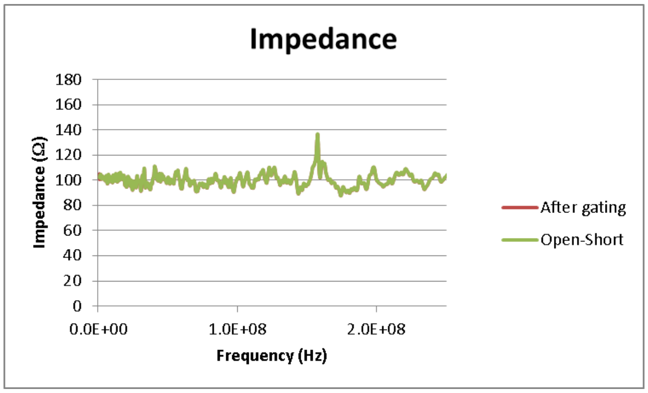

Figure 12. Comparison of final gated impedance with Open-Short reference

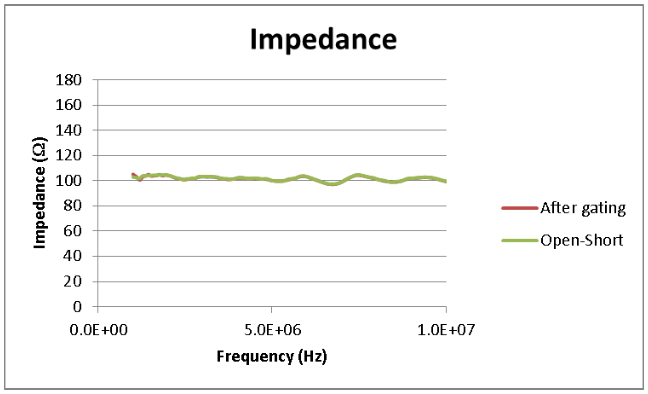

Figure 13. Close-up of the comparison of final gated impedance with Open-Short reference

5. Measurement and computational time considerations

For long cables, the frequency step necessary to access the cable end in the time domain may be quite small. This will lead to large number of measurement points that may drastically increase the measurement and computation time.

In order to solve this issue, the data can be collected using 2 frequency segments with different steps. The low frequency segment will have the necessary low frequency step and must extend above the frequency on which the correction needs to be applied (dependent on cable length and cable insertion loss), whereas the high frequency segment can have any desirable frequency step.

Gating will then be conducted on the lower segment only and both curves will be joined together (after possible need for normalization) to get the final curve. Care must however be taken at the junction of both segments as the gated curve might show spurious effect at segment edges due to the gating process. This can for example be overcome by having an overlap between the 2 segments and discarding the distorted low frequency segment values.

6. Conclusion

Gating in the time domain using Fourier transforms can be used to remove the effect of Open-end for the measurement of Impedance and Return Loss.

In this paper we have demonstrated that gating is a powerful tool to circumvent far-end reflections when measuring cables on drums with not accessible far-end.

Knowledge of Discrete Fourier Transforms properties is however necessary to define the gating process parameters and properly interpret the resultant curves.

7. References

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[4] IEC TR 61156-1-2 standard - Multicore and symmetrical pair/quad cables for digital communications – Part 1-2: Electrical transmission characteristics and test methods of Symmetrical pair/quad cables

8. Authors

Laurent Van Rysselberghe joined AESA in March 2019 as R&D project manager in the field of automatic test equipment. He owns a Bachelor of Science in Electrical Engineering from the Ecole d'Ingénieurs de l'Etat de Vaud in Yverdon HEIG-VD). He had previously worked for 20 years within the cable manufacturing group Nexans. At Nexans, he occupied various positions in high voltage, optical fibres or CATV/radiating cable families as R&D engineer, operational quality manager and production manager of the Cortaillod production plant. He then evolved into the technical expert ladder in electrical performances and testing.

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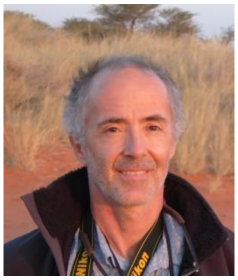
Wolfgang Klein holds a degree of Dipl.-Ing. (TH) Information Technology from RWTH Aachen University (Germany). During and after his university education he worked in the testing department of the German cable manufacturer Kerpenwerk. His responsibilities connected with central IT were related to networking and automating test equipment. In 1994, he joined M.E.A. (Mauf und Rudow) where he used his practical experience to design the Quality Management System CIQ 3.0. He also developed the foundation of some modern telecom automatic test equipment such as the balunless data cable measurement systems “Cobalt”. Since the merger of M.E.A. and AESA, he continues his role as head of the System Development Department.

Boris Dardel obtained his PhD in physics in 1994 at the University of Neuchatel (Switzerland) in Condensed Matter Physics. He then joined the cable manufacture of Nexans Suisse SA in Cortaillod (Switzerland) where he managed different technical departments linked with materials, cable designs, testing and R&D. In 2016, Dr. Dardel came to AESA SA in Bevaix (Switzerland) as R&D Manager, responsible for designing and leading R&D processes.



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