ERL and Impedance Terminology

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14 July 2025

Associated with comments 653, 59-66, 514, 595-599, 611-614

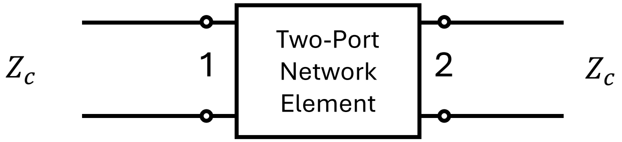
Overview

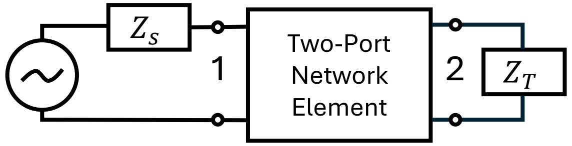
- Several comments against 802.3dj 2.0 suggest changes to the reference impedance Z_0 for scattering parameter calculation and/or measurement
- A precise definition of impedance terms can avoid changing the well-established differential reference impedance of 100 ohms
- Accurate calculation of return loss and insertion loss is still possible even if the characteristic impedance of the channel between network elements differs from the assumed reference impedance of 100 ohms

Terminology

- Restrict our attention to two-port network elements
- Characteristic impedance: a ratio of voltage wave to current wave for a given transmission line or waveguide
  - This is a physical characteristic of the waveguide or transmission line and depends upon material and geometry
- Reference impedance: the impedance assumed at the terminals of a network element for calculating s-parameters, or the impedance load on network ports when measuring s-parameters
  - In general this may be complex, but we will only deal with real reference impedances in this presentation.
- Source impedance: The internal impedance of, or in series with, a source generator attached to the input of a network element
- Termination impedance: The load impedance placed across the output terminal of a network element

No Need to Change Reference Impedance from Well-Established 100 Ohms





- If the characteristic impedance Z_c for the medium is the same on both sides of the element, it makes sense to set $Z_0 = Z_c$
  - What if the characteristic impedance is not the same on both sides?
  - We are using *normalized* s-parameters where the reference impedance is the same for both ports. We could instead use *generalized* s-parameters and use *power waves* instead of voltage waves [1, Sec. 4.3],[2], where $Z_{0,n}$ is specified for each port, but we do not need that complication
- Consider the two-port network element in the upper right, terminated at port 2 with impedance Z_T, and fed with a source of impedance Z_s on port 1.
- We can calculate s-parameters using any arbitrary Z_0
  - If the source impedance and termination impedance match Z_0, then the reflection coefficients at each port are given directly by $s_{1,1}$ and $s_{2,2}$
  - If not, the reflection coefficients can be computed by cascading the s-parameters with the s-parameters of the source and load impedances *using the same* Z_0
- For example, consider the reflection coefficient γ (and hence return loss) at port 1 in the upper right
  - γ depends only on Z_s and Z_{in}, the impedance looking into port 1 of the terminated two-port network element
  - Z_{in} is independent of the reference impedance Z_0 chosen to define $S(Z_0)$
  - The scattering matrix for the cascade of the two-port network element with the terminating load is computed as usual

$$\gamma = \frac{Z_{\text{in}} - Z_s}{Z_{\text{in}} + Z_s}$$

- The return loss (and, in particular, ERL) is independent of the reference impedance used to compute S
  - However, it does depend on Z_T and Z_s, and both should be specified (and not assumed to be Z_0, the reference impedance)

[1] D. M. Pozar, ***Microwave Engineering***, 4th ed., 2012
[2] K. Kurokawa, *Power Waves and the Scattering Matrix,* IEEE Trans. On Microwave Theory and Techniques, March 1965, pp. 194-202

Recommendation

- Keep the well-established differential reference impedance $Z_0 = 100\Omega$
- Compute (or measure) s-parameters for all network elements using the same reference impedance so they can be successfully cascaded
- Explicitly account for source impedance and termination impedance when computing ERL

Appendix: Example Calculation for Lossless Two-Wire Transmission Line

Example: Two-Wire Lossless Transmission Line with Characteristic Impedance Z_c, Phase Constant β, and Length l

- Let Z_0 denote the reference impedance. For an arbitrary Z_0, the scattering matrix, which is a function of the reference impedance, is given by

$$S(Z_0) = \begin{pmatrix} \frac{\left(Z_c^2 - Z_0^2\right)\sin(\beta l)}{\left(Z_0^2 + Z_c^2\right)\sin(\beta l) - 2iZ_0Z_c\cos(\beta l)} & \frac{2Z_0Z_c}{2Z_0Z_c\cos(\beta l) + i\left(Z_0^2 + Z_c^2\right)\sin(\beta l)} \\ \frac{2Z_0Z_c}{2Z_0Z_c\cos(\beta l) + i\left(Z_0^2 + Z_c^2\right)\sin(\beta l)} & \frac{\left(Z_c^2 - Z_0^2\right)\sin(\beta l)}{\left(Z_0^2 + Z_c^2\right)\sin(\beta l) - 2iZ_0Z_c\cos(\beta l)} \end{pmatrix}$$

  - This can be computed using ABCD matrices as given in [1, Sec. 4.4]. Or it can be calculated by assuming a Z_0 matching Z_c (given below) and then doing a reference impedance transformation as in https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Electronics/Microwave_and_RF_Design_III_-_Networks_(Steer)/02%3A_Chapter_2/2.4%3A_Generalized_Scattering_Parameters Sec. 2.4.5

- When $Z_0 = Z_c$, matching the reference impedance to the (real) characteristic impedance, this simplifies as expected to

$$S(Z_0)|_{Z_0=Z_c} = \begin{pmatrix} 0 & e^{-i\beta l} \\ e^{-i\beta l} & 0 \end{pmatrix}$$

Calculate the Reflection Coefficient γ for the Transmission Line Terminated with Impedance Z_T Using Real Reference Impedance Z_0

- The s-parameter for the one-port network element Z_T using reference impedance Z_0 is $s_T(Z_0) = \frac{Z_T - Z_0}{Z_T + Z_0}$
- Cascading this with $S(Z_0)$ gives a new one port network element with s-parameter

$$s_{11,\text{cascade}}(Z_0) = S(Z_0)_{1,1} + \frac{s_T(Z_0)S(Z_0)_{1,2}S(Z_0)_{2,1}}{1 - s_T(Z_0)S(Z_0)_{2,2}} = \frac{\sin(\beta l)\,(Z_c^2 - Z_0 Z_L) + iZ_c(Z_0 - Z_L)\cos(\beta l)}{\sin(\beta l)\,(Z_0 Z_L + Z_c^2) - iZ_c(Z_0 + Z_L)\cos(\beta l)}$$

- For $Z_0 = Z_c$, this simplifies to $s_{11,\text{cascade}}(Z_c) = e^{-2\beta l}\frac{Z_T - Z_c}{Z_T + Z_c}$

- Given the reference impedance Z_0, the impedance looking into this one port network element can be computed as

$$Z_{\text{in}}(Z_0) = Z_0\frac{1 + s_{11,\text{cascade}}(Z_0)}{1 - s_{11,\text{cascade}}(Z_0)} = \frac{Z_c(Z_T\cos(\beta l) + iZ_c\sin(\beta l))}{Z_c\cos(\beta l) + iZ_T\sin(\beta l)}$$

- Note that this input impedance is ***independent*** of the reference impedance Z_0 chosen. $Z_{\text{in}}(Z_0) = Z_{\text{in}}(Z_c) = Z_{\text{in}}$
- Therefore the reflection coefficient, given by $\gamma = \frac{Z_{\text{in}} - Z_s}{Z_{\text{in}} + Z_s}$, is independent of Z_0
- This result holds for an arbitrary two-port network.