# Linear time-invariant system theory for numerical lightning transfer function determination

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To obtain lightning transfer functions of realistic systems from numeric simulation generally is a difficult task. The long duration of typical lightning pulses and the associated low-frequency spectra pose challenges to numerical full-wave electromagnetic solvers which, in particular, are associated with stability issues and long computation times (D. Prost, F. Issac, T. Volpert, W.Quenum, and J.-P- Parmantier, *IEEE Trans. on Electromagn. Compat.*, **55**, no.2, (April 2013), pp. 378-384). This applies both to time and frequency domain numerical techniques.

In this contribution it is explained how to use linear time-invariant (LTI) system theory to facilitate the numerical determination of lightning transfer functions. In LTI system theory the responses of linear and time-invariant systems to arbitrary input signals are studied. To obtain a lightning transfer function it therefore is desired to take advantage of appropriately chosen input signals that lead to both stable and time-efficient numerical calculations. General guidelines for advantageous choices of input signals are given but also depend on the type of electromagnetic solver used.

For illustration, lightning transfer functions of a canonical structure are determined both from time domain and frequency domain calculations, using either comparatively short excitation pulses or appropriately selected frequencies. The use of two independent electromagnetic solvers allows verifying the consistency of the results obtained. Compared to the numerical processing of a lightning electromagnetic pulse in time domain, which usually is of the length of a few hundred microseconds, the speed-up can be up to two orders of magnitudes. Having obtained in this way a lightning transfer function in frequency domain it is then immediate to also calculate the time domain response with respect to an arbitrary lightning electromagnetic pulse by Fourier transformation.

The technique and guidelines proposed allow using common electromagnetic solvers to determine lightning transfer functions in a rather efficient way. They finally are compared to recent and alternative techniques which are based on equivalent circuit modelling of lightning transfer functions.