

The Contributions of Prof. Roberto Tiberio to the Incremental Theory of Diffraction for Electromagnetic

Alberto Toccafondi, Stefano Maci, Alessia Polemi,
Matteo Albani, Filippo Capolino

Dept. of Information Engineering, <http://www.dii.unisi.it>
University of Siena, Italy

Introduction

This paper provides a brief review of the fundamental contributions of Prof. Roberto Tiberio to the area of high-frequency (HF) incremental techniques for antennas and scattering problems. It is focused, in particular, to the main features of the Incremental Theory of Diffraction (ITD), originally introduced by Tiberio and S. Maci in the early nineties, and to development of which he has dedicated with great passion until he passed away on May 2, 2005 at the age of 59.

It was during the late 1980s, that Tiberio's research interest was attracted by new emerging techniques for the prediction of the radar cross section of complex objects. In particular he was fascinated by the early work of P.Y. Ufimtsev on the Physical Theory of Diffraction (PTD), which has the ability to overcome the UTD impairment at caustics. In those years, P.Y. Ufimtsev improved his Edge Wave theory within the framework of PTD, so that it remained valid at any observation aspect outside the Keller cone of edge diffraction. Tiberio extended the PTD edge-wave theory to impedance surfaces [1]. In order to overcome some limitations of the PTD, Tiberio started thinking of a new general formulation for treating edge waves. The original idea was to resort to a description of the scattered field directly in terms of fields rather than in terms of currents. The incremental field contribution of the ITD was initially derived from the problem of the infinite wedge under plane wave illumination, on the basis of a simple Fourier-transform pair between the canonical field and the incremental contribution. The final representation, given in terms of a double integral, was uniformly evaluated, thus providing a closed form solution. It was formally presented for the first time by Tiberio at the 1992 IEEE Antennas and Propagation Society Symposium in Chicago [2] and then published in its scalar version on IEEE Trans. on Ant. and Propagat. in 1994 [3]. Later, Tiberio often interacted with Prof. Ufimtsev and Prof. Yaghjian; their discussions centered on ways of interpreting the two incremental theories based on PTD and ITD, respectively. In 1995-96, Tiberio and his research group extended the original formulation to electromagnetic problems [4] and to treat the case when both the source and the observation point are at finite distance from the edge [5].

In 1996-97 Tiberio, with Maci and Toccafondi, introduced a generalization of the ITD localization process to treat any canonical problem with a uniform cylindrical configuration [6]. This generalized ITD is a unified, self-consistent framework for the description of a wide class of practical scattering phenomena. It introduced a localization process based on constructing a suitable spatial integral representation of the 3D canonical Green's function (GF) through a 2D GF factorization. This method was successfully applied, in a unified framework, to both locally-tangent perfectly conducting wedges and moderately sized circular cylinders. In both these cases this theory provided incremental contributions which explicitly satisfied reciprocity and naturally blends into the UTD when the ray field regime is established. This formulation was also successfully applied to the scattering of electromagnetic fields by plane angular sector [7], and extended to the case of the time domain incremental diffraction by a generally curved edge illuminated by an impulsive source [8].

$$G_{2d}(\rho, \rho'; k_\rho'') = L[U(k_\rho'', \rho) \cdot U(k_\rho'', \rho')] \quad (2)$$

where $L[\cdot]$ is a linear operator. Using (2) in (1) leads to

$$\Psi_c(P) = L\left[\frac{1}{2\pi} \int_{-\infty}^{+\infty} U(k_\rho'', \rho) U(k_\rho'', \rho') e^{-jk_z''(z-z')} dk_z''\right]. \quad (3)$$

It is now rather apparent that the argument of L in (3) represents the inverse Fourier transform (FT) of the product of two spectrum functions. As a consequence, by FT analysis it is seen that the integral expression in (3) represents the *spatial* convolution product of two functions

$$\Psi_c(P) = L\left[\frac{1}{2\pi} \int_{-\infty}^{+\infty} u(z''-z, \rho) \cdot u(z'-z'', \rho') dz''\right]. \quad (4)$$

in which $u(\zeta, \rho)$ and $u(\zeta', \rho')$ denote the inverse FTs, with respect to the variable k_z and k_z' of $U(k_\rho'', \rho)$ and $U(k_\rho'', \rho')$ respectively. Finally the desired incremental field contribution at $Q_l(z''=0)$ is found as

$$\psi(Q_l) = L[u(-z, \rho) \cdot u(z', \rho')] \quad (5)$$

The simple FT relationship established in (2)-(4), is referred to as the ITD FT-convolution process. It provides a general, systematic procedure for obtaining incremental field contributions from the Green's function of infinite, uniform cylindrical local canonical problems.

Application to actual structures

In order to provide practical engineering tools, the four fold spectral integral representation for the incremental field contributions obtained in (5), needs to be asymptotically approximated for large r and r' . For this purpose, a specific asymptotic analysis has been conceived and presented in [9].

These results have been used to obtain high-frequency, dyadic, closed form expressions $d\mathbf{E}^d$ for the ITD incremental field contributions for both wedge shaped (Fig 1a) and moderately sized circular cylinder configuration (Fig. 1b)

$$d\mathbf{E}^d(P) = \begin{bmatrix} dE_\beta^d(P, Q_l) \\ dE_\phi^d(P, Q_l) \end{bmatrix} = \begin{bmatrix} D_e(\nu, \phi, \phi') & 0 \\ 0 & D_h(\nu, \phi, \phi') \end{bmatrix} \cdot \begin{bmatrix} E_\beta^i(Q_l) \\ E_\phi^i(Q_l) \end{bmatrix} \frac{e^{-jkr}}{2\pi r}, \quad (6)$$

where $\mathbf{E}^i(Q_l)$ is the electromagnetic incident field at Q_l . Detailed expressions of the diffraction coefficients $D_{e,h}(\nu, \phi, \phi')$ for several canonical structures have been obtained and reported in [9]-[11]. In (6), ν is the value of a spectral variable which satisfies the ITD stationary phase condition [9], and is defined by

$$\cos \nu = \frac{1 - \cos \beta \cos \beta'}{\sin \beta \sin \beta'} \quad \sin \nu = j \frac{\cos \beta - \cos \beta'}{\sin \beta \sin \beta'}. \quad (7)$$

Finally, in order to provide an estimate of the singly diffracted or scattered field by an actual structure the incremental field contribution (6) is distributed and then integrated along the actual edge l of the structure itself

$$\mathbf{E}^d(P) = \int_l d\mathbf{E}^d(P, Q_l) dl. \quad (1)$$

It has been found that this formulation explicitly satisfies reciprocity and leads to a well-behaved description of the field at any incident and observation aspect, including those close to and at the longitudinal coordinate axis of the local canonical configuration. It also may be successfully applied for either complementing ray field methods or providing fringe field augmentations to the PO approximation.

Numerical results obtained applying this technique for estimating the electromagnetic field scattered or radiated by complex structures, will be shown during the oral presentation.

Conclusion

In this paper a brief overview of the Incremental Theory of Diffraction has been presented, of which Prof. Tiberio was the principal author and the main source of inspiration of our contributions. This activity covers only a very small part of his overall significant research contributions in high-frequency electromagnetic, to which he has indefatigably dedicated until he passed away. However, in this short paper, it has not been possible to describe also the excellent human qualities of Roberto. He was a unique individual and we also know we will all keep his memory alive.

References

- [1] G. Pelosi, S. Maci, R. Tiberio, A. Michaeli, "Incremental Length Diffraction Coefficients for an Impedance Wedge," *IEEE Trans. Antennas Propagat.*, vol. AP-40, n.7, July 1992.
- [2] R. Tiberio and S. Maci, "A Spectral Incremental Diffraction Coefficient," *Proc. of IEEE AP-S Int. Symposium, Chicago, 1992.*
- [3] R. Tiberio, S. Maci "An Incremental Theory of Diffraction. Scalar formulation" *IEEE Trans on Antennas and Propagat.*, Vol. 42, n.5, pp. 600-612, May 1994.
- [4] R. Tiberio, S. Maci, A. Toccafondi "An Incremental Theory of Diffraction. Electromagnetic formulation" *IEEE Trans on Antennas Propagat.*, Vol. 43, No. 1, pp. 87-96, Jan. 1995.
- [5] S. Maci, R. Tiberio, A. Toccafondi "Incremental diffraction coefficients for source and observation at finite distance from an edge" *IEEE Trans. on Antennas Propagat.*, Vol. 44, N. 5, pp. 593-599, May 1996.
- [6] R. Tiberio, S. Maci, A. Toccafondi, "An Incremental Theory of Diffraction for Objects with Local Cylindrical Shape," *Transaction on IEICE (invited), Special Issue on Electromagnetic Theory - Scattering and Diffraction*, vol. E-80, no 11, pp. 1367-1373, Nov. 1997.
- [7] S. Maci, M. Albani and F. Capolino, "ITD Formulation for the Currents on a Plane Angular Sector," *IEEE Trans. on Antennas Propagat.*, Vol. 46, N. 9, September, 1998
- [8] F. Capolino, and R. Tiberio, "A Time Domain Incremental Theory of Diffraction (TD-ITD) for a Wedge," *ICEAA (Int. Conf. Electromagnetics and Advanced Appl.)*, Torino, Italy, 10-14 September, 2001.
- [9] R. Tiberio, A. Toccafondi, A. Polemi and S. Maci, "Incremental Theory of Diffraction: A New Improved Formulation," *IEEE Trans. on Antennas and Propagat.*, vol. 52, no. 9, pp. 2234-2243, Sept. 2004.
- [10] R. Tiberio, A. Toccafondi, A. Pippi, "An Incremental Theory of Diffraction Formulation for Local Circular and Elliptic Cylinders," *Proc. of PIERS International Conference*, March 28-31, Pisa, Italy, 2004.
- [11] A. Toccafondi, R. Tiberio, and A. Polemi, "An Incremental Theory of Diffraction for Edges in Impedance Surfaces," *Proc. of the IEEE AP-S/URSI Radio Science Meeting*, vol. 1, pp. 283-286, Columbus, Ohio, USA, June 21-27, 2003
- [12] R. Tiberio, A. Toccafondi, A. Pippi and M. Albani, "Incremental Theory of Double-Edge Diffraction," *Proc. of URSI General Assembly*, New Delhi, India, 23-29 October, 2005.