A Near and Far-Field Projection Algorithm for Finite-Difference Time-Domain Codes

M. J. Barth, R. R. McLeod, and R. W. Ziolkowski

Lawrence Livermore National Laboratory
7000 East Avenue, P.O. Box 808
Livermore, CA 94550, USA

Abstract—The class of problems to which the Finite-Difference Time-Domain (FDTD) method can be applied is extended through the use of near and far-field projection techniques. These methods are developed by applying the equivalence principle to a surface within the FDTD problem space. Algorithms are found to project the equivalent electric and magnetic currents on this surface to any point in space either in the time or the frequency domains. A summary of extensive validation and error checking results is presented which shows the routines to be robust and accurate to within a few percent. As a result, the FDTD approach can be applied to a number of previously impractical problems.

1. INTRODUCTION

Electromagnetic modelling algorithms can be divided into two general categories: integral-equation methods and differential-equation methods. Integral methods, such as the electric field integral equation (EFIE) approach combined with the method of moments (MOM), represent the object under study as a collection of simply shaped conductors and integrate to find the fields at any point in space. Differential methods, on the other hand, represent a region of space containing the object as a well-defined set (grid) of basic elements such as cubes or tetrahedrons. The object of interest, as well as every cell in this grid, can have independent values of the permittivity, permeability, and conductivity. One simply interpolates between the field values obtained at the grid locations to find their values anywhere. Differential methods therefore have the advantage that they can represent more complex material properties, but the disadvantage that they cannot represent large regions of space because of present limitations on computer memory. Thus the discrete methods have been limited to near-field results.

This paper describes a method of extending these differential methods to the far-field, thus removing this liability. Specifically, the equivalence principle is invoked and an algorithm is developed to project the discrete field samples obtained in the computational volume to locations anywhere outside of it. This near-to-far-field projection method will be demonstrated in both the time and frequency domains with a finite-difference time-domain (FDTD) algorithm.

Section 2 of this paper will develop the general theory of field projection, while Section 3 describes its implementation in the FDTD algorithm. Section 4 discusses
our validation of the method, and Section 5 describes the error sources inherent in our approach and their mitigation. Section 6 concludes the paper.

2. THEORY

We start from Schelkunoff's statement of the equivalence principle [1]: A distribution of electric and magnetic currents on a given surface C can be found such that outside C it produces the same field as that produced by given sources inside C; and also the field inside C is the same as that produced by given sources outside C. One of these systems of sources can be identically zero. Our use of the principle is illustrated in Fig. 1. Inside the FDTD computational volume, the $E$ and $H$ fields are sampled over a closed rectangular surface (surface C in the statement above). All scatterers and sources are contained inside this surface, and the FDTD algorithm calculates the resulting fields.

![Figure 1. Equivalence principle as applied to FDTD volume.](image)

Exterior: $E, H = \text{Original Problem } E, H$
Interior: $E, H = 0$

We now imagine a second problem in which the fields exterior to $C$ are the same, but the interior of the surface contains free-space and zero fields. The $E^{\text{tan}}$ and $H^{\text{tan}}$ fields tangential to the surface $C$ can be used to produce equivalent magnetic ($M_s$) and electric ($J_s$) surface currents which, when radiating into free space, will exactly produce the fields external to $C$ and zero fields inside of it. These equivalent currents are given by the expressions:

$$J_s = \hat{n} \times H^{\text{tan}}$$  \hspace{1cm} (1)

$$M_s = E^{\text{tan}} \times \hat{n}$$  \hspace{1cm} (2)
where \( \hat{n} \) is the outward pointing unit normal to the surface \( C \).

Note that both the tangential \( E \) and \( H \) fields are used on the equivalent surface. The equivalent currents produced by these fields are taken to be infinitesimal electric and magnetic dipoles. Since they are in free-space, the resulting fields are well known. For a single dipole in free space oriented in the \( +\hat{z} \) direction, the electric field vectors in the time and frequency domains are given respectively by the expressions [2]:

**Time Domain:**

\[
\overline{E}_r^J(t) = \frac{(\Delta x)^3}{4\pi r} \left[ \frac{2\eta}{r} + \frac{2}{\epsilon r^2} \int_0^t dt \right] \overline{J}_s \left( t - \frac{r}{c} \right) \cos \theta \\
\overline{E}_\theta^J(t) = \frac{(\Delta x)^3}{4\pi r} \left[ \mu \frac{d}{dt} + \frac{1}{\epsilon r^2} \right] \overline{J}_s \left( t - \frac{r}{c} \right) \sin \theta \\
\overline{E}_\phi^M(t) = -\frac{(\Delta x)^3}{4\pi r} \left[ \frac{1}{c} \frac{d}{dt} + \frac{1}{r} \right] \overline{M}_s \left( t - \frac{r}{c} \right) \sin \theta
\]

**Frequency Domain:**

\[
\overline{E}_r^J(\omega) = \frac{e^{-jkr}}{4\pi r} \overline{J}_s(\Delta x)^3 \left( \frac{2\eta}{r} + \frac{2}{j\omega \epsilon r^2} \right) \cos \theta \\
\overline{E}_\theta^J(\omega) = \frac{e^{-jkr}}{4\pi r} \overline{J}_s(\Delta x)^3 \left( j\omega \mu + \frac{1}{j\omega \epsilon r^2} + \frac{\eta}{r} \right) \sin \theta \\
\overline{E}_\phi^M(\omega) = -\frac{e^{-jkr}}{4\pi r} \overline{M}_s(\Delta x)^3 \left( \frac{j\omega}{c} + \frac{1}{r} \right) \sin \theta
\]

where superscripts refer to the source of the field, subscripts to its direction, \( \Delta x \) is the FDTD grid spacing in meters, \( r \) is the distance from the dipole to the sample points in meters, \( \eta = \sqrt{\mu/\epsilon} \) is the free-space wave impedance in ohms, \( \mu = 4\pi \times 10^{-7} \) is the vacuum permeability in henrys per meter, and \( \epsilon = 8.854 \times 10^{-12} \) is the vacuum permittivity in farads per meter. The quantities in brackets in (3)-(5) are treated as operators acting on the quantities to the right, the result then being evaluated at the requisite retarded time. The total field at a sample point is then the sum of the contributions from all the dipoles on the sampling surface.

A common simplification to these formulas is the “far-field” assumption. At large distances from the source, only the \( 1/r \) terms remain significant, and one is left with diverging spherical waves of the form:

**Time Domain:**

\[
\overline{E}_\theta^J(t) = \frac{(\Delta x)^3}{4\pi r} \mu \frac{d}{dt} \overline{J}_s \left( t - \frac{r}{c} \right) \sin \theta \\
\overline{E}_\phi^M(t) = -\frac{(\Delta x)^3}{4\pi r} \frac{1}{c} \frac{d}{dt} \overline{M}_s \left( t - \frac{r}{c} \right) \sin \theta
\]
Frequency Domain:

\[ E_{\theta}^f(\omega) = \frac{e^{-jkr}}{4\pi r} j\omega \mu \mathcal{J}_s(\Delta x)^3 \sin \theta \]  

\[ E_{\phi}^f(\omega) = -\frac{e^{-jkr}}{4\pi r} \frac{j\omega}{c} M_s(\Delta x)^3 \sin \theta \]  

Conversely, the region in \( r \) where all of the terms are significant is referred to as the "near-field." One is then presented with four distinct problems: time-domain far-field, time-domain near-field, frequency-domain far-field, and frequency-domain near-field. Only the first three of these cases are of significant interest and were addressed, as described in the next section.

3. IMPLEMENTATION

This section discusses the implementation of the projection algorithm in the FDTD code TSAR (Temporal Scattering and Response), developed at Lawrence Livermore National Laboratory. TSAR is a modular FORTRAN code with extensive pre- and post-processing tools that is designed for algorithm development problems such as this one. As mentioned above, only three of the four projection cases were implemented. The first and most used of these is TFAR, the time-domain, far-field projector.

TFAR

The TFAR (Time-domain FAR-field) package in TSAR produces \( E_{\theta}(t) \) or \( E_{\phi}(t) \) at one or more far-field points. By summing the dipole contributions in (9) and (10), one is left with sums of terms over all similar dipoles on the surface \( C \). For instance, the far-field \( E_{\theta} \) component involves a sum over all the electric dipoles on \( C \):

\[ \sum_i \frac{d}{dt} J_i \left( t - \frac{r_i}{c} \right) \]  

The first problem encountered in implementing the TFAR package is due to the spatial staggering of the field components in the FDTD grid [3]. There is no one surface \( C \) which contains both tangential \( E \) and \( H \) fields because of the staggered grid nature of the FDTD method. The effects of this source of error will be discussed in Section 5.

Our solution is to take \( C \) to be in the plane of the tangential \( E \) fields and to interpolate tangential \( H \) fields to this plane simply by averaging the magnetic field values immediately inside and outside the surface \( C \). For instance, for the \( XY \)-plane:

\[ \mathcal{J}_s(x, y, z) = \hat{n} \times \frac{1}{2} \left[ \overline{H} \left( x, y, z + \frac{\Delta z}{2} \right) + \overline{H} \left( x, y, z - \frac{\Delta z}{2} \right) \right] \]  

The time derivative in (13) must be approximated using the discrete temporal samples available from the time-stepping FDTD code. This approximation is another one of the major error sources in the TFAR package. The number of
samples used to approximate this derivative (or the "order" of the derivative approximation) will strongly influence the behavior of the algorithm. Larger orders should yield more accurate approximations to the derivative, but they will incur greater numerical noise due to their greater number of operations. Our study of this question indicates that the optimum choice is a third-order approximation:

\[ \frac{d}{dt} f(n \times \Delta t) \approx c_1 f((n - 1) \times \Delta t) + c_2 f((n) \times \Delta t) + c_3 f((n + 1) \times \Delta t) \]  

(15)

The implementation of this third-order differential requires some care. When the problem begins, a forward-difference version must be used. Similarly, during the final steps of the problem, a backward difference formulation must be employed. This algorithm is difficult to implement, and the associated storage requirements of this method are too excessive.

The alternative is to "unfold" (15) and treat it instead as a recipe for how the value of \( f(t) \) at each time step contributes to the derivatives nearby in time. For example, the value of \( f \) at time step \( (n - 1) \) contributes \( c_1 f((n - 1) \times \Delta t) \) to the derivative at time step \( n \). In this way it is not necessary to store the values of the surface fields, only to apply the value at each time step to the proper derivative equations. The different approximations that are necessary at different times can then be handled by simple logic.

This reduces the storage to be a record, at each far-field point, of the contributions of each component of \( J \) or \( M \) at each time step. The procedure, then, is to examine an \( E \) field value, say, on the surface \( C \) and then produce the equivalent magnetic current dipole \( M \). The time delay from this dipole to the far-field point and the interpolation factors to produce the derivative appropriate for this time step are calculated. The proper amount of the dipole strength is then added to several time slots in the far-field record. The procedure for an \( H \) field is identical except that the temporal staggering of the FDTD algorithm must be taken into account when calculating the time delay. When the problem has completed, the current contributions to the time-records at each far-field point may then be used to calculate the requested \( E \) fields.

This procedure calculates the far-field \( E \) field components radiated from the FDTD problem space at any specified location in space as a function of time. The ability to project these fields in the time-domain is very important, since it preserves the ability of FDTD to simulate true time-domain problems. The next projection method is similar save that the complete field expressions in (3)-(5) are used, allowing the probe point to be near the FDTD volume.

**TNEAR**

The time-domain near-field projector, TNEAR, is similar to TFAR, discussed above, except that the \( 1/r^2 \) and \( 1/r^3 \) terms of (3)-(5) are included in the calculations. Note that one expects the vector projections to be more difficult since there are additional vector terms in the projection. Also, the projected field now depends on the dipole current function, its derivative, and its integral. Each of these terms \( (f(t), \frac{d}{dt} f(t), \text{and } \int f(t) dt) \) is approximated again by a third order
discrete formula. These discrete formulas are “unfolded,” and the value at each step is applied to the calculation at the proper nearby steps. In particular, forward, middle, and backward differences are used at the beginning, middle, and end of the problem, just as in TFAR.

The major implementation difference between TNEAR and TFAR is the necessity of keeping an accumulation of the integral of each dipole strength. This calculation of the integral is unavoidable; it adds considerable storage requirements to the routine: one variable for each field component in the surface C must be stored. Except for this storage requirement, TNEAR behaves in the same manner as TFAR, producing the requested fields at any point in space.

The TNEAR projection algorithm essentially enables the user of the FDTD code to ignore the physical limits of the computational volume when examining the fields. Probes can be placed anywhere in space, without regard to their location inside or outside the actual FDTD computational grid.

**FFAR**

While these projection methods are essential to extending the FDTD algorithm in the time-domain, sometimes it is useful or desirable to examine the fields in the frequency domain. For instance, if an array is excited with a set of chirped pulses, the angular pattern of the array at the carrier frequency is of interest. To produce this with TFAR, one would have to place a number of TFAR points in the far-field, then Fourier transform each one, extract the desired frequency component, and assemble the pattern. The following projection method makes that approach unnecessary.

The frequency-domain far-field projector, FFAR, operates in a similar manner to the previous projection algorithms, except that the frequency-domain nature of the routine makes several operations easier and more accurate. For example, the derivatives are now taken in a simple manner by multiplying the requisite quantities by \( j\omega \). This makes FFAR more accurate than its time-domain counterpart since this frequency-domain derivative is much more precise than the third-order interpolation formulas used in TFAR. Also less difficult to obtain are the propagation delays calculated for the time-domain projections which become simple phase shifts in the frequency-domain.

At the heart of the FFAR algorithm is the method of taking the Fourier transform. The FDTD code is still run in a pulsed, transient mode. As the fields (and thus the currents on the equivalent dipoles) fluctuate, a Fourier transform is taken at the frequency of interest. This is done by transforming (13) to the frequency-domain in the following manner:

\[
j\omega \sum_{n=0}^{N} \sum_{i} f_i(n\Delta t) e^{-j\omega n\Delta t}
\]

This gives the desired frequency-domain derivative of (13) at the particular frequency \( \omega \). The frequency \( \omega \) is taken to be a continuous, arbitrary variable, so that no inaccuracies are introduced by interpolating to the frequency of interest. This
implies several things about the far-field time record. A fundamental property of the Fourier transform requires the sample spacing in the frequency domain to be the inverse of the length of the time-domain record. Thus, a continuous frequency variable indicates that the time-record must be infinitely long. This extension of the time-record, often called “zero-padding,” can be accomplished only if the signal has decayed to a steady-state value of zero. If too few time-steps are simulated and the far-field signal has not fully damped out, its truncation will introduce errors into the frequency-domain data.

The operation of FFAR, then, is to specify (at the desired frequency) a set of points in space where the field values are desired. The FDTD space is driven with a pulse containing that frequency, and the pattern is calculated. As is customary, the pattern is normalized by the factor $e^{jkR}/R$. Since the FDTD algorithm is driven with a multi-frequency pulse, patterns at multiple frequencies can be calculated at once. This is an important difference from Taflove’s approach [4], which requires the FDTD space to be driven with a single frequency pulse until the system reaches steady-state and thus the only information available is at that particular frequency.

These three algorithms, TFAR, TNEAR, and FFAR, were coded in FORTRAN 77 and interfaced to the FDTD code TSAR. The new projection code was approximately 9000 lines long with 25 subroutines. Obviously, extensive validation of the routines was in order.

4. VALIDATION

In order to investigate the sources and magnitudes of error in the projection algorithms, their results were compared with well-established, accurate solutions for a well-defined class of problems – dipole arrays and simple scatterers [5]. Arrays of infinitesimal dipoles can be easily simulated in a FDTD code like TSAR, and the analytic solutions can be directly found. This does not require the FDTD code to contain any scatterers, however, and errors introduced from FDTD scattering inaccuracies might be overlooked. As a second type of test, the frequency-domain, method of moments code NEC [6] was chosen as the standard solution for a dipole array blocked by a T-shaped metal scatterer of various sizes.

The particular geometries chosen were a 1 x 2 dipole array and a 3 x 5 dipole array, each with or without a T-shaped metal scatterer of various sizes. Each problem was run numerous ways: in NEC with various wire spacings and in TSAR with various grid sizes. NEC to NEC comparison (with different segment lengths) served to give us an estimate of the error bars on the NEC results. Variations in the TSAR grid size were used to gauge the dependence of accuracy of the projection technique on grid size and will be discussed below. In total, 267 comparisons were performed and 24 error tables compiled. In this paper, we shall give a small sampling to indicate the trend of these results.

The geometry of a typical scattering problem is shown in Fig. 2. The elements of the 3 x 5 dipole array are separated by approximately 15 cm or exactly $\lambda/2$ at the 1 GHz frequency of interest. A conducting metal “T” made of two metal bars 3 cm thick and 30 cm long is placed 15 cm in front of the array. The TSAR
FDTD code simulated this geometry with a computational space made up of \( 70 \times 90 \times 70 \) cells, each \( 0.02997925 \) meters on a side. The cell size was chosen so that the array elements would lie precisely on the grid locations. The dipole elements were driven with a pulse described algebraically by:

\[
f(\tau) = \begin{cases} 
  96\tau^2 - 192\tau^3, & \text{for } 0 \leq \tau \leq 0.5 \\
  -96(1 - \tau)^2 + 192(1 - \tau)^3, & \text{for } 0.5 \leq \tau \leq 1.0 
\end{cases}
\]  

This pulse was chosen for the continuity of its derivative and integral and was scaled in time to give the desired frequency content. Figure 3 shows a comparison between the \( E_\theta \) patterns predicted by NEC and FFAR at the pulse center frequency of 1 GHz for this problem. The mean error between the two curves is one half of one percent.

![Figure 2. 3 x 5 dipole array with “T” blockage.](image)
Figure 3. 1 GHz far-field $E$ for $3 \times 5$ dipole array with "T".

Figure 4. Time-domain far-field $E$ for $3 \times 5$ dipole array.
Figure 4 shows a comparison in the time domain between the analytic predictions and the TFAR results for the $3 \times 5$ dipole array with no scatterers. Each element of the array was driven with a sine-wave modulated Gaussian with a full-width half-max of $\tau = 0.667$ nsec and a center frequency of 1.5 GHz:

\[ f(t) = \sin(2\pi ft) e^{-4\ln(\frac{1}{2})(t/\tau)^2} \]

(18)

The observation point is along the array axis at 1000 meters. The comparison is again seen to be excellent; the mean error is less than one percent.

As can be seen from these figures, the projection algorithms are reasonably accurate in both the time and frequency domains. The actual errors found are discussed in the next section.

5. ERROR SOURCES

Several sources of errors can be identified in the projection method. An unavoidable error will be any inaccuracies in the FDTD data such as dispersion and discretization noise. After this, the most obvious inaccuracy is the discrete nature of the FDTD samples which leads to interpolation errors in evaluating the currents at the requisite retarded times. This puts inherent limits on the accuracy of the projection calculations. Related to this is the issue of the staggered nature of the grid, which requires that the $H$ fields be interpolated in space to the same locations as the $E$ fields (see Section 3), introducing further errors.

Figure 5. Two dipole verification geometry.
These errors were quantified by studying the problem of two dipoles oriented along the $Z$ axis and separated by 30 cm (see Fig. 5). The dipoles were driven with the pulse (16); the wavelength of the center frequency, 1.0 GHz, is 30 cm. Thus the dipoles are separated by $1.0\lambda$ at the center frequency.

The effect of finite-difference errors can be seen in Fig. 6. The $E_\theta$ pattern was computed for the array by TFAR in two ways. First, the FDTD code was removed and the field samples on the surface $C$ were calculated analytically. Next, the same projection was performed using data supplied by the FDTD code TSAR. In both cases, the results were compared to a 1000 element NEC prediction and the average error throughout the angular pattern was found. The difference between the curves in Fig. 6 is then the error introduced by the FDTD approximation. The FDTD grid spacing was chosen to be $\lambda/10$ at 1.0 GHz, or 3 cm. As the wavelength decreases, the sampling density also decreases and at 1.3 GHz the effects of the decreased sample density begin to show. Below this frequency, however, the errors in the FDTD data are seen to be comparable to the analytic results.

![Figure 6. Average error vs. frequency for two sets of fields on surface $C$.](image)

The effect of the discrete grid size can be seen in a typical error plot shown in Fig. 7. The plot shows the angular average error, as defined above, between FFAR and NEC. The upper, solid curve is for a TSAR cell size of 3 cm (one tenth of a wavelength at 1 GHz), while the lower, dashed curve is for a cell size of 1.5 cm (one twentieth of a wavelength at 1 GHz). As can be seen, the finer sampling density produces more accurate far-field projections. Also, the error increases with increasing frequency due to both the dispersion errors of FDTD and the decreasing sample density. The implication of both Fig. 6 and 7 is that errors will be small if the grid density is kept larger than at least 10 cells per wavelength for the minimum wavelength of interest in the pulse.
Figure 7. Average error vs. frequency for two sample densities.

The frequency-domain projection, FFAR, suffers from a further source of error: the discrete Fourier transform (DFT) to the frequency-domain. Several common error sources associated with the DFT such as leakage and picket-fence are eliminated by our infinite extension of the time record. Aliasing, however, is not removed as easily. Aliasing, the appearance of high-frequency terms in the lower frequencies, is also a serious problem for the FDTD routine. Thus, the accuracy of both FDTD and FFAR depends on the frequency content of the drive pulse. For best results, all significant energy in the drive pulse should be below a frequency corresponding to ten FDTD cells per wavelength.

6. CONCLUSIONS

This paper has introduced an extension to the traditional FDTD algorithm which significantly decreases one of its strongest liabilities: the limited size of the computational volume. Now, in the manner of integral equation methods, fields can be calculated at any location in space through the use of time and frequency domain projection algorithms.

These algorithms have been implemented in the Lawrence Livermore National Laboratory FDTD code TSAR and have been tested extensively. Results show them to be accurate to a few percent, which is in the same range as the FDTD algorithm itself. Comparisons with theory and the NEC code have shown that the domain of accurate solutions is the same as that for the FDTD method; thus the projection routines do not restrict the applicability of the FDTD algorithm.
Indeed, we feel that the applicable range of FDTD is greatly expanded by the addition of this capability. One can now model time-domain antennas, far-field scattering, and simulate mutual interactions at arbitrary distances. The addition of near- and far-field projection capability to the FDTD algorithm greatly increases the number of problems that can be treated with this discrete method.

ACKNOWLEDGMENT

The Editor thanks J. Oates, D. Sheen, and one anonymous Reviewer for reviewing the paper.

REFERENCES


Marvin J. Barth was born in Lima, Ohio, on March 21, 1931. His engineering education consisted of the B.S. degree from the United States Naval Academy (1954), the M.S. degree from the Air Force Institute of Technology (1960), and the Ph.D. degree from Syracuse University (1965). Dr. Barth served as a regular officer in the U.S. Air Force from 1954 to 1975 and his assignments included Rome Air Development Center (1959-63), Air Force Cambridge Research Laboratory (1965-66), the faculty of the U.S. Air Force Academy (1966-71), and the Air Force Weapons Laboratory (1971-75). From 1975 to 1979 he attended Law School and taught at the University of Washington (J.D. and M.B.A.). He then returned to engineering and worked for Boeing Aerospace Corp. before coming to his present employment at Lawrence Livermore National Laboratory in 1981. His interests are theoretical and computational electromagnetics.

Robert R. McLeod was born in New Hartford, N.Y., on July 27, 1962. He received a Bachelor of Science in electrical engineering with highest honors from Montana State University in 1984. In 1985, he earned a Master of Science in electrical engineering in the same institution. In 1985 he joined the Fields, Materials, and Plasma Modeling group of the Lawrence Livermore National Laboratory. While at the lab, he earned a Master of Science degree from the University of California at Davis in applied science. His research interests include numerical modeling of waves and scattering, optics, and optical computing.

Richard W. Ziolkowski was born in Warsaw, N.Y., on November 22, 1952. He received the Sc.B. degree in physics magna cum laude with honors from Brown University in 1974, the M.S. and Ph.D. degrees in physics from the University of Illinois at Urbana-Champaign in 1975 and 1980, respectively. He was a member of the Engineering Research Division at
the Lawrence Livermore National Laboratory from 1981 to 1990 and served as the leader of the Computational Electronics and Electromagnetics Thrust Area for the Engineering Directorate from 1984 to 1990. Dr. Ziolkowski joined the Department of Electrical and Computer Engineering at the University of Arizona as an Associate Professor in 1990. His research interests include the application of new mathematical methods to linear and nonlinear problems dealing with the interaction of acoustic and electromagnetic waves with scattering objects, plasmas, and dielectric materials. Dr. Ziolkowski is a member of Sigma Xi, Phi Kappa Phi, the American Physical Societies, and Commission B of URSI (International Union of Radio Science). He served as the Vice Chairman of the 1989 IEEE/AP-S and URSI Symposium in San Jose and is currently serving as a member of the URSI Commission B Technical Activities Committee.