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Mohammed Serhir

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Transient UWB Antenna Near-Field and Far-Field Assessment from Time-Domain Planar Near-Field Characterization: Simulation and Measurement Investigations

Mohammed Serhir, Member, IEEE

Abstract— In this paper we present the experimental validation of Time-Domain (TD) Near-Field to Near-Field (NFNF) and Near-Field to Far-Field (NFFF) transformations for UWB antenna transient characterization. The used computation schemes for near-field to near- or far-field transformations are based on the Green’s function representation of the radiated field where NF and FF are directly calculated in the time domain. The first step of the validation process comprises the electromagnetic simulation results dedicated to evaluate the accuracy of NFNF and NFFF transformations. The second step uses near-field measurement data of a Vivaldi antenna to validate the developed computation schemes whereas the measurement and calibration procedures are fully described. The measured NF data using Supelec planar and cylindrical near-field facilities are also compared with the electromagnetic simulation transient results of the Vivaldi antenna.

Index Terms— Time domain, antenna measurement, near-field far-field transformation,

I. INTRODUCTION

F or Ground Penetrating Radar applications we are interested in measuring the free space transient response of Ultra Wide Band (UWB) antennas composing the radar [1][2]. The duration of the transient response is of a crucial importance and the designers try to shorten the antenna free space impulse response while enlarging its frequency bandwidth of matched input impedance ($S_{11}<-10$dB) [3]. More generally, GPR using UWB non-dispersive antennas provides easily interpretable radargrams [4][5].

UWB antennas transient characterization can be carried out using NF or FF techniques [6][7]. Based on the Huygens principle, the NF measurement techniques make use of the tangential components of electric or magnetic field collected over a scan surface in the vicinity of the AUT. Then, these measured data are transformed to calculate the electromagnetic field at different distances [8]. The NF measurements can be conducted in a small and low cost anechoic chamber and by time-gating the measured data, one can filter out multiple reflections occurring during the measurement [9][10]. This allows the data accuracy enhancement especially for low frequency measurement in small anechoic chambers for which the absorption quality is unsatisfactory. The TD techniques permit also the radiation pattern measurement in non-anechoic environment as presented in [11-14]. They are well adapted for studying the parasitic electromagnetic radiation emitted from electronic devices for electromagnetic compatibility purposes [15].

Even the theoretical development of the NFNF and NFFF transformations are detailed in [6][16][17], the experimental utilization of TD NF techniques are less popular than the FD techniques. This is due to difficult experimental implementation combined with the drawback related to the computer time requirement, which could make unrealistic the application of the technique to cases of practical interest. The transient NF measurement systems use wideband and small probes with low interaction with the AUT [18]. Moreover, in NFNF and NFFF transformation schemes the measured E-field and its time derivative are involved in the calculation process. The accuracy of the NFNF and NFFF transformation results depends on the highest point of the chosen interpolation technique to keep working with the minimum number of measured data [19]. In this paper, we use the reconstruction formula to calculate and interpolate the E-field and its time derivative as well for NFNF and NFFF transformation schemes.

Here we aim at validating NFNF and NFFF transformations using the experimental measurement and the electromagnetic simulation software CST MWS [20]. An UWB Vivaldi antenna designed for Ground Penetrating Radar (GPR) is used for this purpose. The Vivaldi TD NF data are collected at different distances from the antenna. First, the NFFF transformation results are presented in order to outline the errors due to the measurement surface truncation. Second, we evaluate the accuracy of the NFNF calculation using different set of measured NF data collected at different distances from the AUT. Third, we present the experimental validation of the NFNF transformation scheme we have developed based on the Green’s function representation. Our algorithms are applied to data obtained from the measurement of the Vivaldi antenna in

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M. Serhir is with Laboratoire Genie electrique et electronique de Paris (GeePs) (UMR 8507 CentraleSupelec - CNRS – UPSud - UPMC) 11 rue Joliot-Curie - Plateau de Moulon 91192 Gif sur Yvette Cedex - France, (e-mail: mohammed.serhir@centralesupelec.fr).
II. PLANAR NEAR-FIELD TRANSFORMATION FOR FORWARD PROPAGATION

Let us consider UWB Vivaldi antenna. This is used to validate NFNF and NFFF transformation algorithms. The antenna has been optimized for the frequency band (0.5 GHz - 3 GHz) and its S11 is presented in Fig. 1. In this paper we have adopted the NFNF and NFFF transformation algorithms based on the Green’s function representation where NF and FF are determined directly in the time domain. This choice has been made to clearly distinguish our work from the NFNF or NFFF transformations based on modal expansions (plane wave expansion in the frequency domain) [15].

A. Planar Near-Field to Near-Field transformation

Using the NF tangential components measured over the planar surface at the distance x_meas from the AUT the NFNF transformation algorithm allows calculating the transient field at different distances in the half space x ≥ x_meas. The NFNF transformation is expressed as [6, eq. (5.6)] [16]

\[
E(\mathbf{r},t) = -\frac{1}{2\pi} \int \int_{S} \int \int_{S} \frac{1}{R^2} \left[ \frac{\partial E_{\text{meas}}}{\partial t} \left( \mathbf{r}, t - R/c \right) \right] dydz + \frac{1}{R^2} \left[ \frac{\partial E_{\text{meas}}}{\partial t} \left( \mathbf{r}, t - R/c \right) \right] \Delta y_{0} \Delta z_{0},
\]

for x ≥ x_meas.

The calculated field \( \bar{E}(\mathbf{r},t) \) in the left side of (1) is expressed at the observation point \( \mathbf{r} = x\mathbf{i} + y\mathbf{j} + z\mathbf{k} \) at the instant t as a function of field \( \bar{E}_{\text{meas}}(\mathbf{r}_{0}, t - R/c) \) and its time derivative \( \partial \bar{E}_{\text{meas}}(\mathbf{r}_{0}, t - R/c)/\partial t \). These are measured at the position \( \mathbf{r}_{0} = x_{\text{meas}} \mathbf{i} + m\Delta y_{0} \mathbf{j} + n\Delta z_{0} \mathbf{k} \) at the instant \( t - R/c \) with...
\[ \vec{R} = \vec{r} - \vec{r}_{\text{min}}, \quad R = |\vec{r} - \vec{r}_{\text{min}}| \quad \text{and c is the free space light velocity.} \]

As presented in Fig. 2, the measurement surface is defined for \(-D_{\text{max}} \leq \gamma_{\text{meas}} \leq D_{\text{max}}\) and \(-D_{\text{max}} \leq \zeta_{\text{meas}} \leq D_{\text{max}}\). The NF is sampled regularly using the Nyquist criterion \(\Delta t = \frac{\pi}{f_{\text{max}}}\), \(\Delta y_0 = \Delta z_0 = \pi c / f_{\text{max}}\) with \(f_{\text{max}}\) being the maximum angular pulsation of the AUT excitation signal, \(N_y = D_{\text{max}} / \Delta y_0\) and \(N_z = D_{\text{max}} / \Delta z_0\).

From (1) the first step in NFNF transformation is the interpolation of the measured field \(\vec{E}_{\text{meas}}(\vec{r}_{\text{mon}}, t)\) and its time derivative to set their values at the instant \(t - R/c\). The accuracy of NFNF transformation depends on the chosen interpolation method. In our analysis, we use the reconstruction formula to interpolate and assess the time derivative of the measured field at \(t - R/c\).

Let us consider NF data measured over the scan surface at \(x_{\text{meas}}\) from the AUT. This NF is a band limited function that can be accurately interpolated using the reconstruction formula. Namely, the field \(\vec{E}(\vec{r}_{\text{mon}}, t)\) at the instant \(t\) in the time window \(t_0 \leq t \leq t_0 + (N_t - 1)\Delta t\) is calculated using the field samples \(\vec{E}(\vec{r}_{\text{mon}}, t_0 + l\Delta t)\) with the cardinal series as follows [6][17]

\[
\vec{E}(\vec{r}_{\text{mon}}, t) = \sum_{l=0}^{N_t - 1} \sin \left( \frac{\pi}{\Delta t} \right) \left[ \vec{E}(\vec{r}_{\text{mon}}, t_0 + l\Delta t) \right]
\]

\[
= \sum_{l=0}^{N_t - 1} h(t) \vec{E}(\vec{r}_{\text{mon}}, t_0 + l\Delta t)
\]

with \(h(t) = \sin \left( \frac{\pi}{\Delta t} \right) \), for \(t_0 \leq t \leq t_0 + (N_t - 1)\Delta t\) (2)

This means that in the time window \(t_0 \leq t \leq t_0 + (N_t - 1)\Delta t\) and provided the NF is sampled respecting the Nyquist criterion \(\Delta t = \frac{\pi}{f_{\text{max}}}\), the time derivative of the E-field is expressed as

\[
\frac{\partial \vec{E}}{\partial t}(\vec{r}_{\text{mon}}, t) = \sum_{l=0}^{N_t - 1} \frac{\partial h(t)}{\partial t} \vec{E}(\vec{r}_{\text{mon}}, t_0 + l\Delta t)
\]

with \(\frac{\partial h(t)}{\partial t} = \frac{1}{\Delta t} \left[ \cos \left( \frac{\pi}{\Delta t} \right) - h(t) \right] - h(t)\) (3)

In our analysis we use (2) and (3) to calculate the E-field and its time derivative between time-samples (at \(t - R/c\)) provided the sampling Nyquist criterion is respected. This criterion, which is linked to spatial NF sampling \(\Delta y_0 = \Delta z_0 = c\Delta t\), is sufficient to accurately perform the NFNF transformation.

### B. Planar Near-Field to Far-Field transformation

The time domain NFFF transformation is formulated as [6, eq. (5.57)][16][17]

\[
\vec{E}_{\text{FF}}(\theta, \varphi, t) = -\frac{1}{2\pi c} \int_{-\infty}^{\infty} e^{-j\omega t} \left( \vec{E}_{\text{meas}}(\vec{r}, t) \right) \cdot \left( \vec{r} \times \frac{\partial \vec{E}_{\text{meas}}}{\partial t} \right) d\omega, \quad \text{for } \omega \geq \omega_{\text{max}}
\]

\[
\varphi = \pi \sin \vartheta \cos \varphi - \cos \theta \sin \varphi
\]

The antenna radiation pattern at the far-field distance \(\vec{E}_{\text{FF}}(\theta, \varphi, t)\) is written as a function of the time derivative of the tangential measured NF \(\partial \vec{E}_{\text{meas}}/\partial t\).

The spherical coordinates \((\theta, \varphi)\) are associated with the planar coordinates system \((x, y, z)\). \(\vec{r}_0 = \vec{r}/|\vec{r}| = \cos \vartheta \sin \varphi \cos \varphi + \sin \vartheta \cos \varphi\) is the FF observation direction and the measured field data \(\vec{E}_{\text{meas}}\) are collected at \(\vec{r}_0(x_{\text{meas}}, y_{\text{meas}}, z_{\text{meas}})\). As expressed in (4), the finite integration is truncated and we implicitly suppose that the field is weak beyond the measurement surface edges. However, one of the advantages of time-domain near-field measurements is that one can obtain exact early-time far-field pattern values even though the field outside the scanned area is strong.

In the next sections, we present the validation results of the NFNF and NFFF transformation using simulation and measurement results and the E-field time derivative calculated using (3).

### III. Electromagnetic Simulation Results

We have developed a routine expressing (4) to study the NFFF transformation results when using different NF data collected at different measurement planes \(x_{\text{meas}}\). The Vivaldi antenna has been simulated using the transient simulator of the CST MWS to provide the NF data. The AUT is excited using a cosinusoidal voltage modulated by Gaussian signal to cover the AUT frequency band (0.5 GHz - 3.5 GHz), \(e(t) = \cos(\omega_0(t - t_0))e^{-j\omega_0^2t^2}\) with \(\omega_0 = 2\pi f_0\), \(f_0 = 1.75\ GHz\), \(\tau = 0.810^{-9}\)s and the delay \(t_0 = 1.75\ \tau\). The excitation signal and its spectrum normalized at \(f_0 = 1.75\ GHz\) are presented in Fig. 3.

The antenna TD NF is collected over the plane \(x = x_{\text{meas}}\) respecting regularly spaced positions \(\Delta y_0 = \Delta z_0\). Based on [6] the bandwidth of the Gaussian signal is approximately equal to \(12/2\pi\). One can sample without any loss of information the radiated field respecting the Nyquist criterion \(\Delta y_0 = \Delta z_0 = \lambda_{\text{min}}/2\), where \(\lambda_{\text{min}} = c/f_{\text{max}}\) and \(f_{\text{max}}\) is the maximum frequency expressed as \(f_{\text{max}} = f_0\pi/12/2\pi = 4.14\ GHz\).
Using the CST MWS we generate the antenna transient radiated NF over the plane $x_{\text{meas}} = 30$ cm. This scan surface is delimited by $D_{z\text{max}} = 100$ cm and $D_{y\text{max}} = 75$ cm as defined in Fig. 2 and the NF in the cut planes $y_{\text{meas}} = 0$ and $z_{\text{meas}} = 0$ are presented in Fig. 4 for Ey and Ez components. The Vivaldi antenna is linearly polarized and the E-field is predominantly radiated through the Ey component and the Ez component is negligible comparatively to Ey.

Since the $S_{11}$ (Fig. 1) of the Vivaldi antenna demonstrates a pass-band behavior (0.5 GHz - 3 GHz), we are interested in evaluating the accuracy of the NFFF transformation as a function of the NF sampling frequency. To do so, we compare the actual FF obtained from the CST MWS with the NFFF transformation results using 3 different NF sampling frequencies $f_1 = 3$ GHz, $f_2 = 3.5$ GHz, $f_{\text{max}} = 4.14$ GHz. In Figs. 5 we present the FF comparison at the observation directions $(\theta = \pi/2, \phi = 0)$, $(\theta = \pi/4, \phi = 0)$ and $(\theta = \pi/2, \phi = \pi/4)$ for the FF components $E_{\theta}$ and $E_{\phi}$.

![Fig. 5. The transient Etheta(V/m) and Ephi(V/m) far-field radiation pattern comparison considering different sampling frequencies for the spatial directions: $(\theta = \pi/2, \phi = 0)$, $(\theta = \pi/4, \phi = 0)$ and $(\theta = \pi/2, \phi = \pi/4)$. The NF data are collected at $x_{\text{meas}}=30$ cm.](image)

![Fig. 6. The transient Etheta(V/m) and Ephi(V/m) far-field radiation pattern comparison considering different NF measurement distances (20 cm, 30 cm 40 cm, 50 cm) for the spatial directions: (a) $\theta=\pi/2$, $\phi=0$, (b) $\theta=\pi/2$, $\phi=\pi/6$.](image)
As seen in Figs. 5, good agreements are noticed between the $E_{\phi}$ (co-polar) component of the actual FF and the ones resulting from NFFF transformations. The use of the sampling frequency $f_1 = 3$ GHz is responsible for the aliasing effects clearly seen for the cross-polarization component $E_{\phi}$. In addition, the differences between the curves of Fig. 5 are due to measurement surface truncation. For the far-field observation point ($\theta = \pi/2$, $\phi = 0$) the difference between the actual FF and the calculated one starts at $t = 5.11\tau$ that corresponds to the arrival time when the center of the pulse reached the measurement edge $D_{z_{\text{max}}} = 75$ cm. The error corresponding to the measurement edge $D_{z_{\text{max}}} = 100$ cm is visible around $t = 6.10\tau$.

Using the sampling frequency $f_{\text{max}} = 4.14$ GHz, we compare the NFFF results calculated from NF data collected at different planes $x_{\text{meas}} = 20$ cm, 30 cm, 40 cm, 50 cm. These calculated FF are compared in Figs. 6 with the actual one at the directions ($\theta = \pi/2$, $\phi = \pi/6$) and ($\theta = \pi/3$, $\phi = 0$). As presented in Figs. 6, good agreements are noticed for $2.5\tau \leq t \leq t_{\text{tr}}$, where $t_{\text{tr}}$ depends on the measurement distance $x_{\text{meas}}$ and the FF observation point ($\theta$, $\phi$). This effect is known as the truncation error and the FF reliable region is defined by $\alpha_0$ and $\alpha_\phi$ expressed in Fig. 2 depends on the measurement distance.

Based on the presented simulation results, the developed NFFF transformation routine has been validated using the CST MWS. The NFFF transformation results have shown a satisfactory accuracy while using the Nyquist criterion for NF sampling.

The next comparisons aim at validating the TD NFNF transformation routine. For this, we provide tangential NF data at $x_{\text{meas}} = 20$ cm for $-75$ cm $\leq y_{\text{meas}} \leq 75$ cm and $-100$ cm $\leq z_{\text{meas}} \leq 100$ cm sampled using $f_{\text{max}} = 4.14$ GHz. Thereafter, we perform the NFNF transformation routine to calculate the field at 50 cm from the AUT. The NFNF transformation results ($E_{\text{NF2NF}}$) are compared with the actual NF ($E_{\text{ref}}$) at the plane cuts ($x = 50$ cm, $y = 0$, $-100$ cm $\leq z \leq 100$ cm) and ($x = 50$ cm, $-75$ cm $\leq y \leq 75$ cm, $z = 0$) using the error expressed as:

$$\text{error}(y, z, t) = 100 \frac{E_{\text{ref}} - E_{\text{NF2NF}}}{\max[E_{\text{ref}}]}$$

(8)

The error values are presented in Figs. 7 for the $E_y$ and $E_z$ components. As it is seen, the NFNF transformation errors are very low for the $E_y$ components (co-polar) and reaches $5\%$ at the edges of the measurement surface ($y = \pm 75$ cm and $z = \pm 100$ cm) for $E_z$ component (cross-polar). These errors are due to NF measurement surface truncation. In Figs. 8, the calculated AUT transient radiated fields $E_y$ and $E_z$ are compared with the actual ones at different observation points $A(x = 50$ cm, $y = 0$, $z = 0$), $B(50$ cm, 25 cm, 0), $C(50$ cm, 0, 70 cm), $D(50$ cm, 50 cm, 0), $E(50$ cm, 0, 98 cm) and $F(50$ cm, 72 cm, 0). The calculated NF agrees very well with the actual one even for the observation points $E$ and $F$ situated in the area of high error values (maximum $5\%$) of Figs. 7.

To get a deep insight into the origin of the NFNF transformation errors we calculate the field at $x = 50$ cm from the AUT using NF data collected over the scan planes $x_{\text{meas}} = 10$ cm and 30 cm. These are compared with the actual NF (the CST MWS) at the plane cuts ($x = 50$ cm, $y = 0$, $-100$ cm $\leq z \leq 100$ cm) and ($x = 50$ cm, $-75$ cm $\leq y \leq 75$ cm, $z = 0$). The resulting error values are presented in Figs. 9 (a) and (b). From Figs. 7 and Figs. 9 we can conclude that the calculated results are completely unreliable outside of a certain spectral region. The erroneous ripples are due to the discontinuity of the measured field at the edge of the truncated surface. Hence, the
entire calculated pattern is always affected by errors, and it is not possible to define a region where the error is completely zero. However, the concept of the spectral reliable far-field region is usually applied to refer to the region in which the error is not negligible but is low [21].

From Figs. 7 and Figs. 9, the highest error value over the principal component $E_y$ stay stable around 3%. In Figs. 7 and Figs. 9 (a) corresponding to NF data collected at $x_{\text{meas}} = 10$ cm and 20 cm, the truncation error is higher in the region $-50 \text{ cm} \leq y \leq 50 \text{ cm}$ and $-75 \text{ cm} \leq z \leq 75 \text{ cm}$ in comparison with the results of $x_{\text{meas}} = 30 \text{ cm}$. The truncation error is directly linked to the level of the discontinuity of the measured field at the edge of the truncated surface. At $x_{\text{meas}} = 10$ cm and 20 cm this discontinuity is more important than for $x_{\text{meas}} = 30 \text{ cm}$.

Up to now, we have studied the accuracy of NFFF and NFNF transformation routines using electromagnetic simulation software (the CST MWS). In the next section we describe the experimental validation of the developed transformation routines.

IV. MEASUREMENT RESULTS

The Vivaldi antenna used in the simulation presented above has been fabricated and Supelec planar NF range to measure its radiated field is presented in Fig. 10. The Vivaldi antenna and the measurement probe are placed inside the anechoic chamber of dimensions $4 \text{ m} \times 5 \text{ m} \times 3 \text{ m}$. We measure the tangential near-field components $E_y$ and $E_z$ while moving the probe respecting a regular spacing $\Delta y = \Delta z = 3 \text{ cm}$ between measurement points over the planar surface ($-60 \text{ cm} \leq y_{\text{meas}} \leq 60 \text{ cm}$ and $-60 \text{ cm} \leq z_{\text{meas}} \leq 60 \text{ cm}$) at $x_{\text{meas}} = 10 \text{ cm}$ in front of the antenna. For our measurement investigations we have used the wideband probe “En- Probe EFS-105” [22]. This probe is composed of a small dipole (dimensions $6.6 \text{ mm} \times 6.6 \text{ mm}$) connected to the base unit through a fiber optic link and the base unit is connected to the measuring VNA through a short cable. This probe is dedicated to NF measurement covering the frequency band ($5 \text{ MHz} - 3 \text{ GHz}$). The probe performances can be extended to $3.5 \text{ GHz}$ with slight measurement sensitivity degradation in the frequency band ($3 \text{ GHz} - 3.5 \text{ GHz}$).

The antenna NF measurement is carried out in the frequency band ($0.3 \text{ GHz} - 3.5 \text{ GHz}$) using a Vector Network Analyzer (Agilent ENA 5071b). Thereafter the measured frequency-domain NF complex data (amplitude and phase) are Fourier transformed to set the TD NF of the Vivaldi antenna when excited by the pulse given in Fig. 2. In Fig. 10, we compare the measured TD NF at the point ($x_{\text{meas}} = 10 \text{ cm}$, $y_{\text{meas}} = 0$, $z_{\text{meas}} = 0$) with the one obtained from the CST MWS. The $E_y$ component (co-polar) fits well the CST results. However, the $E_z$ component (cross-polar) shows some discrepancies.

Fig. 10. (left) The Supelec planar measurement setup used for NF antenna measurement. The Vivaldi antenna is placed at 10 cm from the measuring probe (En-probe EFS 105). The probe displacements (translation in y and z directions) are controlled by automated process. (right) The Vivaldi antenna transient radiated field ($E_y$ (left) and $E_z$ (right)) in the boresight direction is presented and compared with the CST MWS results after the calibration procedure (normalization).

Fig. 9-a The error values of $E_y$ and $E_z$ at the plane cuts $y = 0$ and $z = 0$ resulting from the NFNF transformation: the NF data is measured at $x_{\text{meas}} = 10 \text{ cm}$ and transformed to calculate the field at 50 cm from the AUT.

Fig. 9-b The error values of $E_y$ and $E_z$ at the plane cuts $y = 0$ and $z = 0$ resulting from the NFNF transformation: the NF data is measured at $x_{\text{meas}} = 30 \text{ cm}$ and transformed to calculate the field at 50 cm from the AUT.
The NF probe used in this measurement campaign is supposed to behave like a point source. For probe calibration procedure, we have normalized the measured NF magnitude (co-polar) in order to reach the CST MWS maximum NF level. This is performed at the principal direction ($x_{\text{meas}} = 10$ cm, $y_{\text{meas}} = z_{\text{meas}} = 0$) and the normalization coefficient is applied to measured NF data (Ey and Ez) over the measurement surface.

In Figs. 11 we compare the measured NF at $x_{\text{meas}} = 10$ cm with the CST MWS NF data after the calibration step. The agreements are very satisfactory for Ey component meanwhile the cross-polarization (Ez) shows some differences compared with the CST results. This is due to many reasons: in part to the antenna fabrication accuracy, measurement positioning errors (alignment), cross-polarization of the probe is not well defined, probe sensitivity for low field levels....

Using the NFNF routine we transform the NF data measured at plane $x_{\text{meas}} = 10$ cm to calculate the field at the spatial positions A ($r = 2.44$ m, $\theta = \pi/2$, $\varphi = 0$), B ($r = 2.44$ m, $\theta = \pi/2$, $\varphi = \pi/6$), C ($r = 2.44$ m, $\theta = \pi/3$, $\varphi = 0$) and D ($r = 2.44$ m, $\theta = \pi/6$, $\varphi = 0$). The reference antenna radiation patterns used for these comparisons have been measured at Supelec cylindrical NF measurement facility placed in an anechoic chamber of dimensions $6 \text{ m} \times 7 \text{ m} \times 8 \text{ m}$. This measurement facility is presented in Fig. 12 and the E-field is measured using the same probe as the planar NF range (En-probe EFS-105) at the plane cuts $\theta = \pi/2$ and $\varphi = 0$. For our comparison, we consider the CST NF data ($x_{\text{meas}} = 10$ cm) which are transformed to reach the spatial positions A, B, C and D. These comparisons are carried out for the Ey components (co-polar) and are presented in Figs. 13. As it is seen, good agreements are noticed between the measurement results. The NFNF transformation yields satisfactory results when using NF data measured at 10 cm from the AUT and transformed in order to calculate the transient response at the positions A, B, C. The differences observed for the position D are due to the NF measurement surface truncation error. The CST MWS NF collected at 10 cm is also transformed to calculate the field at the positions A, B, C and D. This has been done in order to verify that our calibration procedure stay correct and no additional calibration step is needed to compensate for the probe spatial response (the probe acts actually as a point source).

The NFNF transformation allows calculating Ex, Ey and Ez components in the half space $x \geq x_{\text{meas}}$ in front of the AUT using the tangential components measured at a given distance $x_{\text{meas}}$. Indeed, using Vivaldi antenna transient NF measured in the planar NF facility at $x_{\text{meas}} = 10$ cm from the AUT we perform NFNF transformation to set the transient field over the planar surface at $x = 40$ cm ($-60 \text{ cm} \leq y \leq 60 \text{ cm}$, and $-60 \text{ cm} \leq z \leq 60 \text{ cm}$). These are compared with the CST MWS results at the plane cuts ($x = 40$ cm, $y = 0$, $-60 \text{ cm} \leq z \leq 60 \text{ cm}$) and ($x = 40$ cm, $-60 \text{ cm} \leq y \leq 60 \text{ cm}$, $z = 0$). As it is seen in Figs. 14, the NFNF transformation results fit well the simulated Ey component (co-polar). The normal component Ex for the plane cut $y = 0$ agrees well with the simulated results. However, low level fields (cross-pol) present many discrepancies compared with the CST MWS results. Generally, the results of NFNF and NFFF transformations present some difficulties to set accurately the low-level cross-polarization field since the cross-polarized NF component is difficult to measure accurately with the EFS-105 probe (Fig. 10).
Finally, using the NF data measured at $x_{\text{meas}} = 10$ cm in the planar NF facility we perform NFFF transformation to calculate the transient far-field over the plane cut ($\theta = \pi/2$, $-\pi/2 \leq \phi \leq \pi/2$). The NFFF results are Fourier transformed to determine the AUT radiation pattern in the frequency domain. These are compared in Fig. 15 with the actual FF obtained from the CST MWS at the frequencies 1.5 GHz, 2 GHz and 2.5 GHz. The comparison includes also the TD NFFF transformation results of the CST MWS NF data collected at $x_{\text{meas}} = 10$ cm from the AUT and the measured field in the cylindrical measurement facility at 2.44m from the AUT. From Fig. 15, a satisfactory agreement is noticed between the TD (time-domain) NFFF and the CST MWS FF results for the angular region $-48 \text{ deg.} \leq \phi \leq 48 \text{ deg.}$ Beyond this area ($\phi \leq 48 \text{ deg.}$ and $\phi \geq 48 \text{ deg.}$) the differences between the different curves are due to the measurement surface truncation.

V. CONCLUSION

This paper has presented the experimental validation of Time-Domain (TD) Near-Field to Near-Field (NFNF) and Near-Field to Far-Field (NFFF) transformation for antenna transient characterization. Based on the Green’s function representation we have derived NFNF and NFFF transformation calculation schemes which have been validated using electromagnetic simulation software and experimental measurement data. The studied Vivaldi antenna radiated transient field has been measured and near-field to far-field transformations have resulted in a good accuracy compared with the CST MWS simulated transient field. The NFNF transformation can also be used to determine the normal components of the radiated transient field. In addition, the frequency domain comparison have shown a satisfactory agreement.
accuracy for far-field calculation.

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