STRD and Near Field Modeling of Metallic Wedges for Optical Detection Systems

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Abstract—We analyze an accurate approach based on the Simultaneous Transverse Resonance Diffraction (STRD) modeling. The new method allows to evaluate by means of transmission line circuits the near field generated by a metallic wedge excited by an optical source. The STRD technique is implemented in the rigorous multipole expansion of the Green's function (MEG) theory by providing a modeling of material permittivity detection for wireless micro/nano systems. A good agreement between finite element method (FEM), finite difference time domain (FDTD) and STRD/MEG results is found. Requiring a low computational cost, the proposed modeling is suited for electromagnetic simulators.

Index Terms—Metallic wedges modeling, optical detection system, plasmon probes, wireless sensing.

I. INTRODUCTION

CONCENTRATION of optical energy below the diffraction limit has many diverse applications. They include near-field microscopy [1], single-molecule biochemical sensing [2], miniaturized integrated optics [3], high-density data storage [4], non-linear optics [5], surface enhanced Raman scattering or fluorescence [6], and implanted wireless systems [7]. Metallic wedges are suitable for these applications because they can focus the energy in proximity of the discontinuity and they behave as probes for optical detection systems. The optical source is a surface plasmon wave which can be enhanced by a nano/micro grating placed directly on the probe [8]. An example of optical near field detection system is reported in Fig. 1(a) where a transmitter metallic wedge T_x , excited by an optical wave, radiates the focused electromagnetic field, and, a receiver wedge probe R_x detects the variation of the refractive index dn (dielectric contrast) in a background with refractive index n . The distance and the orientation of both probes will be defined in order to distinguish without errors the refractive index variation. Being the near field difficult to evaluate at optical frequencies an accurate approach able to model and design the T_x/R_x wedge detection system is necessary: the electromagnetic field near the discontinuity of the metallic conductor is irregular and the detection principle becomes impossible. The Simultaneous Transverse Resonance Diffraction

Fig. 1. (a) Schematic diagram of a radiation system with metallic wedges: the transmitter metallic wedge T_x is excited by an external optical source and the receiver wedge probe R_x detects the variation of the electromagnetic field related to a variation of the refractive index dn . (b) Volume V and surface S used for the calculus of the near field.

(STRD) method allows to calculate the near field singularity by distinguishing the near field from the irregular field and consecutively the noise from the signal. The micro-nano scale of antennas requires an accurate modeling especially for near field applications. The traditional numerical approaches such as finite element method (FEM), and finite difference time domain (FDTD) technique require high computational cost for the evaluation of the radiated field in proximity of a dielectric or metallic discontinuity. For this purpose we use the new approach of multipole expansion of the Green's function (MEG) based on the novel principle of STRD [9]: the STRD/MEG was previously applied for the near field evaluation of three dimensional dielectric corner by showing a good convergent solution with a low computational cost and with a reduction of the computational time of 17/10 times if compared with the traditional numerical methods [9]. For the first time in the proposed work we apply the STRD/MEG method to a particular class of antennas obtained as wedge conductors appropriate for plasmon resonance probe systems: the same approach described in [9] for dielectric optical waveguides is implemented and modified in order to consider surface plasmon wave (SPW) excitation propagating along an optical waveguide with thin film metallic layer and radiated by a metallic wedge discontinuity.

At optical frequencies the analysis of the electromagnetic (EM) field radiated from metallic wedges becomes difficult and the traditional FDTD and FEM approaches could fail. Convergent FDTD/FEM solutions, related to the detection of low dn

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values by means of wedge discontinuities, require high computational cost and consecutively complex parallel computing implementations also under the hypothesis of plasmon resonance condition. The new STRD/MEG method overcomes the problem of the high computational cost correlated to the solution accuracy because takes into account the EM singularity, it is easy to implement, and provides good convergent solutions.

We summarize our work in the points listed below. In particular

- i) we formulate the STRD modeling of a metallic wedge probe system by implementing the MEG approach;
- ii) we calculate the near field for different wedge configurations;
- iii) finally we compare the STRD/MEG results with the three dimensional (3-D) FEM and FDTD ones for a radiation system probes operating at $\lambda_0 = 1 \mu\text{m}$.

II. MULTIPOLE EXPANSION OF THE GREEN'S FUNCTION

The radiated electric field at an external point P of region with refractive index n of Fig. 1 is expressed as [10], [11]

$$\mathbf{E}(P) = \frac{1}{j\omega 4\pi\epsilon_c} \nabla \times \nabla \times \left(\int_V \mathbf{J}_i G(\mathbf{r}, \mathbf{r}') dV_Q \right) + \int_S (\mathbf{H} \times \hat{n}) G(\mathbf{r}, \mathbf{r}') dS_Q - \frac{1}{4\pi} \nabla \times \left(\int_S (\hat{n} \times \mathbf{E}) G(\mathbf{r}, \mathbf{r}') dS_Q \right) - \frac{\mathbf{J}_i}{j\omega\epsilon_c} \quad (1)$$

where in spherical coordinates the wedge point is at $Q = Q(r', \theta', \varphi')$, and the field is evaluated at $P = P(r, \theta, \varphi)$ where is located the R_x probe. The volume V used in (1) is enclosed by the spherical surface S as illustrated in Fig. 1(b). The spherical surface is centred in the singularity point Q.

The permittivity $\epsilon_c = n^2$ indicates the cladding permittivity. The cladding encloses the wedge. In spherical coordinates, the Green function satisfies the Helmholtz scalar equation and the multipole expansion of the Green's function given by [10]–[22]

$$G(\mathbf{r}, \mathbf{r}') = \sum_{l,m} g_l(r, r') Y_{l,m}^*(\theta', \varphi') Y_{l,m}(\theta, \varphi). \quad (2)$$

We observe that (2) presents a discontinuity peak of the first derivative at the point Q (point of singularity). According with this property the MEG is suited for near field evaluation in proximity of metallic singularities. Moreover the index l indicates the order of the expansion and represents the accuracy of the solution: the convergence of the near field solution can be performed by increasing the order of MEG. A solution of Maxwell's equation in cylindrical coordinates is provided by the following three field components

$$\begin{aligned} E_\rho &= -j\omega\mu \frac{1}{\rho} \frac{\partial \Phi}{\partial \phi} \\ E_\phi &= j\omega\mu \frac{\partial \Phi}{\partial \rho} \\ H_z &= k^2 \Phi \end{aligned} \quad (3)$$

where Φ is a suitable Hertzian potential which satisfies Helmholtz' equation. The field in (3) is TE with respect to the z -direction, briefly TE^z , but it is also TM with respect to

Fig. 2. Perfectly conducting wedge infinite in the z -direction. (a) 3-D-view; (b) geometry in the transverse plane also showing the cylindrical coordinate system.

TABLE I
BEHAVIOUR OF TE^z FIELD NEAR A METALLIC WEDGE

Geometry	ν	E_ρ, E_ϕ	H_z
conductor	$\nu = \pi/\Psi_1$	$\propto \rho^{\nu-1}$	$\propto \rho^\nu$
conductor	$\nu = 2/3$	$\propto \rho^{-1/3}$	$\propto \rho^{2/3}$
conductor	$\nu = 1/2$	$\propto \rho^{-1/2}$	$\propto \rho^{1/2}$

the ϕ -direction (thus TM^ϕ). A similar modal analysis can be carried out for TM^z (i.e., TE^ϕ) fields characterized by the following components

$$\begin{aligned} H_\rho &= j\omega\epsilon \frac{1}{\rho} \frac{\partial \Phi}{\partial \phi} \\ H_\phi &= -j\omega\epsilon \frac{\partial \Phi}{\partial \rho} \\ E_z &= k^2 \Phi. \end{aligned} \quad (4)$$

Equations (3) and (4) are used in order to calculate the total electric field (1) near the metallic wedge by using the relationships which convert the cylindrical coordinates to spherical coordinates. In particular, (3) and (4) are the fields used in (1) as $\mathbf{E}$ and $\mathbf{H}$, they takes into account the singularity of the EM field and allow to distinguish the TE analysis from the TM one. The TE and the TM approaches are related to the TE or TM polarization of the source.

III. SIMULTANEOUS TRANSVERSE RESONANCE DIFFRACTION MODELING AND SINGULARITY EVALUATION

It is well recognized that, in many cases, boundary and radiation conditions alone are not sufficient to determine the solution uniquely [9], [23], [24]. In any case it is possible to construct several different fields which satisfy these conditions [9]. In particular, by considering the metallic wedge reported in Fig. 2, the MEG approach well matches the radiation conditions especially for the near field calculation, but an accurate evaluation of the potential Φ is requested.

The ρ -dependence of the Φ potential can be written, in general, as combination of Bessel and Hankel functions. In particular, since no source is present in $\rho = 0$ the excitation arrives in Q but it is not localized in Q), the ρ -dependence is completely

TABLE II
BEHAVIOUR OF TM^z FIELD NEAR A METALLIC WEDGE

Geometry	ν	H_ρ, H_ϕ	E_z
$\nu = \pi/\Psi_1$	$\propto \rho^{\nu-1}$	$\propto \rho^\nu$
$\nu = 2/3$	$\propto \rho^{-1/3}$	$\propto \rho^{2/3}$
$\nu = 1/2$	$\propto \rho^{-1/2}$	$\propto \rho^{1/2}$

Fig. 3. (a) A perfect conducting wedge and N dielectric wedges. The z axis is along the common wedge and normal to the figure. (b) Equivalent transmission line circuit: δ_i represent the electric lengths and ζ_i the characteristic impedance, respectively. (c) conducting wedge embedded in a material with refractive index n , and (d) equivalent transmission line circuit.

described by Bessel functions. For this reason, near the edge, we may use the small argument approximation of the Bessel function by the trigonometric dependence on the angle ϕ thus providing the following form of the potential

$$\Phi(\rho, \phi) = \frac{1}{k_0^2} \rho^\nu [A_i \sin(\nu\phi) - B_i \cos(\nu\phi)] \quad (5)$$

where $k_0 = 2\pi/\lambda_0$ is the free space wave number and λ_0 is the optical working wavelength, the near field will be characterized by the singularity ν which can be calculated by a circuital approach. If the metallic wedge is embedded in N dielectric materials, as indicated in Fig. 3(a), the circuital approach takes into account the electromagnetic field propagating along the cascade of transmission lines of Fig. 3(b). Each transmission line is characterized by an electric length $\delta_i = \nu \Psi_i$ (which is function of the angle Ψ_i related to the dielectric material ϵ_i), and by a characteristic impedance ζ_i [12]. The simultaneous resonance of the transmission lines will provide the singularity ν of the electromagnetic field. The resonance condition is performed by annulling the total impedance of the circuit with respect to a reference plane [12]. If the conductor is embedded in a single dielectric material $\epsilon_1 = \epsilon_c = n^2$ as reported in Fig. 3(c), the

equivalent transmission line circuit of the metallic edge will be a single transmission line enclosed in two short circuit (see Fig. 3(d)).

Let us consider for simplicity a transverse electric TE-polarized (H_z, E_ρ, E_ϕ) field. By defining the following equivalent voltages and currents related to the scheme of Fig. 3(a)

$$V_i = \frac{1}{\epsilon_i} [A_i \cos(\nu\phi_i) + B_i \sin(\nu\phi_i)]$$

$$I_i = [A_i \sin(\nu\phi_i) - B_i \cos(\nu\phi_i)] \quad i = 1, \dots, N \quad (6)$$

and by making use of the continuity of H_z and E_ρ components we derive the following transmission matrix ($ABCD$) representation [25]

$$\begin{pmatrix} V_{i+1} \\ I_{i+1} \end{pmatrix} = \begin{pmatrix} \cos(\nu\phi_i) & \zeta_i \sin(\nu\phi_i) \\ \zeta_i^{-1} \sin(\nu\phi_i) & \cos(\nu\phi_i) \end{pmatrix} \begin{pmatrix} V_i \\ I_i \end{pmatrix} \quad (7)$$

where $\zeta_i = 1/\epsilon_i$ is the normalized TM^ϕ characteristic impedance. By introducing the load impedance $Z_i = V_i/I_i$ and $T_i = \tan(\nu\Psi_i)$ and by using the standard formula for the impedance transformation along a transmission line:

$$Z_i = \zeta_i \frac{Z_{i-1} + j\zeta_i T_i}{\zeta_i + jZ_{i-1} T_i} \quad i = 1, 2, \dots, N \quad (8)$$

we can calculate the simultaneous resonance condition of the total impedance $Z_1 + Z_2 =$ in the case of $N = 1$ (case of Fig. 3(c)) where Z_1 and Z_2 are the impedances calculated starting from the reference plane of Fig. 3(d). In this case we have that $T_1 = 0$, that is

$$\nu = \frac{\pi}{\Psi_1} \quad (9)$$

By applying the resonance condition to different wedge geometries we obtain the singularity ν of the TE^z and TM^z near field reported in Tables I and II, respectively. We note that according with Fig. 2 the angle Ψ_1 is equal to $2\pi - \alpha$.

IV. SOURCE CHARACTERIZATION: SURFACE PLASMON WAVE AND PLASMON RESONANCE

According to (2) the STRD-MEG is based on the expansion of spherical harmonics which allows to obtain a very accurate solution regarding radiation problems. These functions must be matched with the source in order to improve the exact solution of the physical problem. In particular for the STRD-MEG approach we use as input field of the antenna a surface plasmon

Fig. 4. (a) Plasmon waveguide and excitation of a surface plasmon wave impinging on an integrated plasmonic antenna (metallic wedge). (b) Example of SPW for a waveguide with $\epsilon_c = 3.1$, $\epsilon_a(\text{air}) = 1$, d (thickness of a gold layer) = 50 nm, and operating at $\lambda_0 = 1 \mu\text{m}$.

wave (SPW) generated by the plasmon waveguide of Fig. 4(a). Assuming as source an electric field, impinging with an angle β on the thin film metallic layer reported in Fig. 4(a), the resulting surface electromagnetic wave will have the following general form

$$\begin{aligned} \mathbf{A}_1 &= \mathbf{A}_{10} e^{i(\mathbf{k}_{z1}z + \mathbf{k}_{y,EW}y - \omega t)} & z > 0 \\ \mathbf{A}_2 &= \mathbf{A}_{20} e^{i(\mathbf{k}_{z2}z + \mathbf{k}_{y,SPW}y - \omega t)} & z < 0 \end{aligned} \quad (10)$$

where $\mathbf{A}$ stands for $\mathbf{E}$ and $\mathbf{H}$, k_{z1} and k_{z2} are the wavevectors in the z -direction, $k_{y,EW}$ and $k_{y,SPW}$ are those in the x -direction and ω is the angular frequency. The incident light coming from the dielectric material reflects at the metallic interface and localized light, called evanescent field (EW), occurs. The EW excites the surface plasmon wave reported in Fig. 4(b) (the plot is obtained by fixing the geometrical and the optical parameters) which is propagating along the surface of the metal film and thus, a part of the incident light is absorbed. The light intensity of the reflected ray will depend on the incidence angle θ . The propagation constant of the EW is expressed as

$$k_{y,EW} = \frac{2\pi}{\lambda_0} \sqrt{\epsilon_c} \sin \theta \quad (11)$$

Fig. 5. Calculated gold permittivity versus the working wavelength λ_0 .

Fig. 6. TE^z near field radiation pattern of the near electric field for a conductor wedge with $\Psi_1 = 2\pi$ and for (a) $l = 1$ and (b) $l = 3$. The plots are calculated by fixing $z = 0.1 \text{ nm}$.

where λ_0 is the working wavelength. The propagation constant of the SPW wave is given by the following expression [26], [27]:

$$\begin{aligned} k_d &= \frac{2\pi}{\lambda_0} \left(\frac{\epsilon_a \epsilon_m}{\epsilon_a + \epsilon_m} \right)^{1/2} \\ k_r &= -k_d \left(\frac{2}{\epsilon_a - \epsilon_m} \right) \left(\frac{\epsilon_a \epsilon_m}{\epsilon_a + \epsilon_m} \right)^{3/2} \\ &\quad \times \exp \left\{ i \frac{4\pi d}{\lambda_0} \left(\frac{\epsilon_m}{(\epsilon_a + \epsilon_m)^{1/2}} \right) \right\} \end{aligned} \quad (12)$$

where k_d is the dispersion relation of the surface plasmon wave of a metal-vacuum interface in a one-sharp-boundary model, k_r is the perturbation to k_d due to the physical volume of the metal defined by the thickness d , and the complex dielectric function of a metallic film can be expressed in the following form:

$$\epsilon_m(\omega) = \epsilon'_m(\omega) + i\epsilon''_m(\omega) \quad (13)$$

When (11) and (12) satisfy the following equation, the surface plasmon resonance occurs and a part of incident light is absorbed

$$k_{y,SPW} = k_d + k_r. \quad (14)$$

At the resonance condition the infinitely metal conductor placed at the end of the waveguide will be coupled and will be radiated as explained in the previous Section III.

Fig. 7. 90° metallic wedge: total TE^z electric field versus $|r - r'|$ and versus different variations dn of refractive index. The order of the MEG expansion is $l = 3$. Inset: schematic plot of the distance $|r - r'|$.

Fig. 8. 90° metallic wedge: comparison between STRD, 3-D FEM and 3-D FDTD total TE^z electric near field versus $|r - r'|$ and for different variations dn of refractive index. The order of the MEG expansion is $l = 3$.

V. RESULTS AND DISCUSSIONS

As application of the STRD approach implemented in MEG theory (STRD/MEG) we fix the working wavelength to $\lambda_0 = 1 \mu\text{m}$ (InGaAsP laser source) and we implement (1) by means of a FORTRAN code. We consider a gold plasmonic antenna. The permittivity is calculated by means of the Brendel-Bormann model [26] (see Fig. 5) by obtaining at $\lambda_0 = 1 \mu\text{m}$ $\epsilon_m' = 38.15$ and $\epsilon_m'' = 3.474$. In order to observe the accuracy of the STRD near field solution with respect to the order l of the MEG expansion of (2), we calculate in Fig. 6 the radiation pattern in the xy -plane of the TE^z field for a conductor with $\alpha = 0$ and for different l values. We note that the infinitely thin metal conductor ($\alpha = 0$) represents a critical case regarding the convergence of the near field solution, therefore it is useful in order to fix the

minimum value of the order l which will perform a close solution for all the geometrical configurations with $\alpha \neq 0$. The TE^z assumption is due to the hypothesis of TE^z optical source excitation, and the total electric field is calculated by (1), by Table I, by supposing the impressed currents $\mathbf{J}_i = 0$, and by integrating over the total surface S and over the total volume V reported in Fig. 1(b). Equations (3), calculated by (5) and (9), are implemented as the $\mathbf{E}$ and $\mathbf{H}$ fields indicated in (1).

We observe from Fig. 6(a) that the solution with $l = 1$ is weakly accurate, while the solution with $l = 3$ reported in Fig. 6(b) is convergent. The uniform intensity of the electric field distribution illustrated in the xy plane of Fig. 6(b) defines a clear shape (similar to an eight) of the near field radiation pattern. This does not happen in the case of Fig. 6(a) where the shape of the field intensity is irregular: in this case discontinuous

regions of intensities are observed as fringes of the boundary, this allows to not establish during the design process the correct position of the point P in the xy plane (point where can be located the receiver wedge probe R_x).

For this purpose the choice of the order for the conductor edges must be at least $l = 3$. We consider now the transmitter/receiver system of Fig. 1 and the case of 90° -metal edge ($\alpha = 90^\circ$) relevant for many practical applications, and, we suppose that the receiver probe R_x is placed at a distance $|\mathbf{r} - \mathbf{r}'|$ which depends on the working wavelength and on the near field region. In order to analyze the probe sensitivity we consider the solution (1) for materials characterized by different dielectric contrasts dn . Figs. 7 and 8 prove that the STRD/MEG approach allows to distinguish the near field amplitudes also for low dielectric contrasts. Observing Fig. 7 we conclude that in this case the receiver probe R_x must be located at a distance between 0.3 and $0.8 \mu\text{m}$ (near field region where it is possible to distinguish the variation of the electric field amplitude). The oscillations observed in Fig. 7 below 0.3 are related to the singularity region characterized by discontinuities of the EM field near the singularity point Q. In the singularity no very closed solutions can be performed. Smaller oscillations can be obtained by increasing the order l of the expansion.

Fig. 8 validates the convergence of the STRD/MEG approach by means of the comparison with 3-D FEM results: a good agreement between 3-D FEM and STRD/MEG results is found. We use for the comparison a properly designed 3-D FEM tool typically used for the design of micrometric structures [9]. The FEM near field region is the region closest to the source, and the 3-D FEM electric field $\mathbf{E}(x, y, z)$ external to the region bounded by a closed spherical surface may be written as [24]

$$\mathbf{E}(x, y, z) = \int_S ((j\omega\mu_0 \mathbf{H}_{\text{tan}})G + (\mathbf{E}_{\text{tan}} \times \nabla G) + (\mathbf{E}_{\text{normal}} \nabla G)) dS \quad (15)$$

where S represents the radiation boundary surface, j is the imaginary unit, $\mathbf{H}_{\text{tan}}$ is the component of the magnetic field that is tangential to the surface, $\mathbf{E}_{\text{normal}}$ is the component of the electric field that is normal to the surface, G is the free space Green's function, given by

$$G = \frac{e^{-jk_0|\mathbf{r}-\mathbf{r}'|}}{|\mathbf{r}-\mathbf{r}'|} \quad (16)$$

being k_0 the free space wave number, and, $\mathbf{r}$ and $\mathbf{r}'$ representing field points and source points on the surface, respectively. The 3-D FEM tool simulates, as in the STRD/MEG case, the radiation of the 90° -metal edge of a perfect metallic square plate with side of $1 \mu\text{m}$ by using a TE^z source. The 3-D FEM modeling of the source is illustrated in Fig. 9(a). According with Fig. 7, a clear variation of dn (corresponding to a near field variation) is checked around $|\mathbf{r} - \mathbf{r}'| = 0.4 \mu\text{m}$. For this reason the FEM R_x probe is placed at a distance of $0.4 \mu\text{m}$ along the y direction of Fig. 9(a).

In Fig. 9(b) we show the 3-D FEM total electric field excited by T_x and coupled with R_x . The total 3-D FEM electric field follows the STRD/MEG radiation pattern illustrated in the inset of Fig. 9(b).

Fig. 9. 3-D FEM modeling of 90° metallic wedge. (a) TE^z optical source. (b) $\mathbf{E}$ total vector field coupled with the R_x probe; inset: STRD/MEG radiation pattern with $l = 3$.

TABLE III
COMPARISON AMONG STRD/MEG, 3-D FEM AND 3-D FDTD
COMPUTATIONAL TIME. THE SYMBOL “*” MEANS: PARALLEL COMPUTING IS
REQUIRED. THE DIFFERENCE BETWEEN THE CASE OF $l = 1$ AND $l = 3$
IS DUE TO THE IMPLEMENTATION OF THE CUMULATIVE SUM FUNCTION

dn Sensitivity	STRD/MEG	3D FEM	3D FDTD
$1 \div 10$	$\cong 3$ min. ($l=1$)	$\cong 20$ min.	$\cong 35$ min.
10^{-1}	$\cong 50$ min. ($l=3$)	$\cong 10$ h.	$\cong 12$ h.
10^{-2}	$\cong 1$ h. 12 min. ($l=4$)	$\cong 13$ h.	$\cong 16$ h.
10^{-3}	$\cong 1$ h. 35 min. ($l=5$)	*	*
10^{-4}	$\cong 1$ h. 55 min. ($l=6$)	*	*
10^{-5}	$\cong 2$ h. 20 min. ($l=7$)	*	*
10^{-6}	$\cong 2$ h. 40 min. ($l=8$)	*	*
10^{-7}	$\cong 2$ h. 58 min. ($l=9$)	*	*

The efficiency of the STRD model is shown in Table III, where we compare the computational (CPU)-time for STRD/MEG, 3-D FEM and 3-D FDTD methods (with a 1-GHz PC, 512/M-RAM). The tetrahedral elements used in the 3-D FEM simulation and the FDTD rectangular mesh have the same length of the space-step of STRD/MEG. The multipole expansion order $l = 3$ employed for the plots of Fig. 6 provides a good convergent solution with a low computational cost, by decreasing the computational time of about 10 times. The order $l = 1$ requires only 3 minutes but the solution is inaccurate. As indicated in the same table, by increasing the order l it is possible to evaluate the effect of very low variations of dn : the numerical detection sensitivity represents the accuracy of the STRD/MEG solution and can be performed in short time (about 3 hours are necessary in order to obtain a sensitivity of 10^{-7}) without parallel computing implementations. For an high sensitivity of FEM and FDTD approaches, the parallel calculus is required: FEM and FDTD do not implement the irregular field due to singularity ν and expanded by the multipole expansion of the Green's function, and, consecutively, very fine meshes are required by overcoming the PC limits. We observe that the

STRD/MEG computational cost can be further decreased by using an implementation suitable with the parallel calculus.

VI. CONCLUSION

We presented in this work a new theoretical model STRD/MGE which provides with a good accuracy and low computational cost the near field generated by a generic metallic edge. The proposed approach is applied for the first time to a well defined metallic probe system by showing an high sensitivity also for the detection of low dielectric contrasts. The STRD/MEG is suited for standard simulators and is able to design plasmon probe for wireless systems.

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