Assignment III Surface Waves

EE4620 Spectral Domain Methods in Electromagnetics

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Abstract

In this assignment, the propagation constant of the TM0 and TE1 surface wave modes is calculated as a function of frequency for two different dielectrics. Furthermore, the field components of the surface wave are evaluated at $f = 10$ GHz, for a dielectric with height $h = 2$ mm and permittivity ϵ_r. Finally, the radiated and surface wave power and surface wave efficiency are calculated.

I. SIMULATIONS

The scripts of this assignment are in the GIT repository Assignment III; and the library developed and used in the scripts is in spectral-methods-library. To run the simulations either place the script and library repositories in the same parent folder or change the library path in the simulation scripts.

II. SURFACE WAVE PROPAGATION CONSTANT

The normalized propagation constants, to the propagation constant in free space k_0, of the TE1 and TM0 surface waves are plotted as a function of the frequency (expressed as a normalized dielectric's height to the wavelength in the dielectric) in Fig.1; the dielectric has a height $h = 2$ mm and permittivity $\epsilon_r = 5$. The TM0 mode starts to propagate at electrically short dielectrics (around $h/\lambda_d = 0.05$). On the other hand, the TE1 starts to propagate at around quarter wavelength dielectric height $h/\lambda_d = 0.25$. Therefore, designing grounded dielectric stratified medias that cut-off the TM0 mode is difficult, as a consequence of the antenna impedance becoming lower as the antenna moves closer to the perfect electric conductor (PEC). However, usual design choice is $h/\lambda_d = 0.25$, at which the impedance is easier to match while the TE1 mode is just in cut-off.

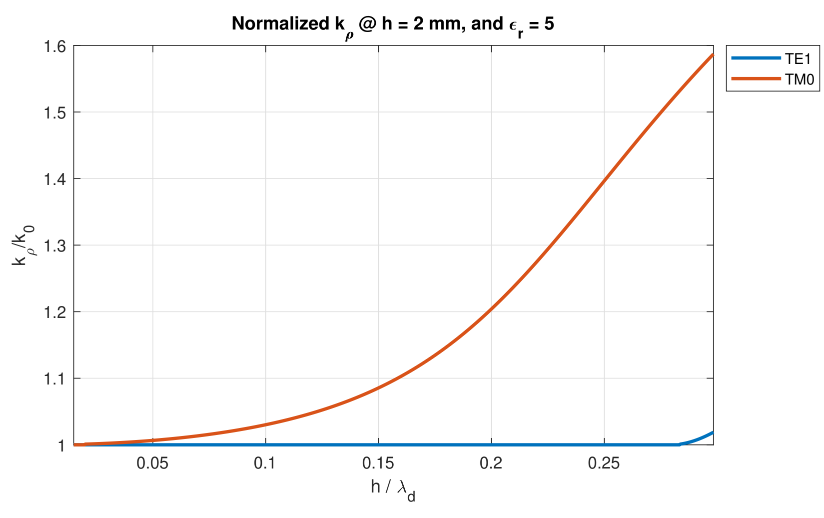

Fig. 1. Propagation constant of the TE1 and TM0 surface waves normalized to k_0 as a function of the dielectric's height normalized to the wavelength for a dielectric with $h = 2$ mm and $\epsilon_r = 5$.

The normalized propagation constants of the TE1 and TM0 surface waves for a dielectric with permittivity $\epsilon_r = 10$ are plotted in Fig.2. The wavelength inside the dielectric is

$$\lambda_d = \frac{c}{\sqrt{\epsilon_r} f}, \tag{1}$$

where c is the speed of light. Therefore increasing the dielectric's permittivity, decreases the wavelength. This decrease in the wavelength results in electrically larger dielectric layers (for the same height), and causes a shift in the propagation constant plot to the left. Therefore for the same height, dielectrics with higher permittivity become electrically larger and start to propagate the TE1 mode at lower frequencies. These effects of the permittivity can be observed when comparing Fig.2 to Fig.1.

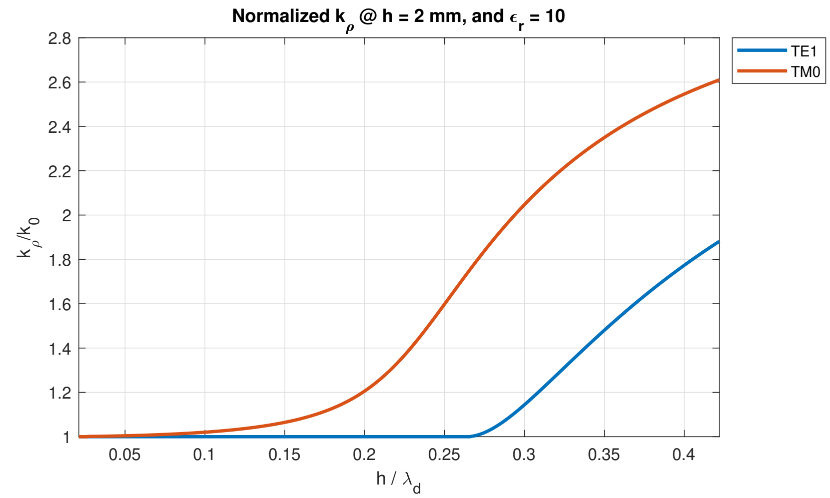

Fig. 2. Propagation constant of the TE1 and TM0 surface waves normalized to k_0 as a function of the dielectric's height normalized to the wavelength for a dielectric with $h = 2$ mm and $\epsilon_r = 10$.

III. Surface Wave Field Contribution

The variation in the real and imaginary parts of the TM0 surface wave components, E_ρ and E_z, are plotted, at $\phi = 0°$ and $h = 1$ mm, as a function of the radial distance ρ, normalized to the wavelength inside the dielectric λ_d, in Fig.3 for $f = 10$ GHz and dielectric with permittivity $\epsilon_r = 10$. The material is non-lossy, however, a decrease in the amplitude is observed with increasing radial distance ρ. This decrease in the amplitude is due to the cylindrical spreading of the cylindrical wave; same power is spread over larger cylindrical area, therefore, causing a reduction in the amplitude when observing one point in ϕ and z for different ρ. The cylindrical spreading (or envelope) is defined by

$$E \propto \frac{e^{-jk_{SW}\rho}}{\sqrt{\rho}}. \tag{2}$$

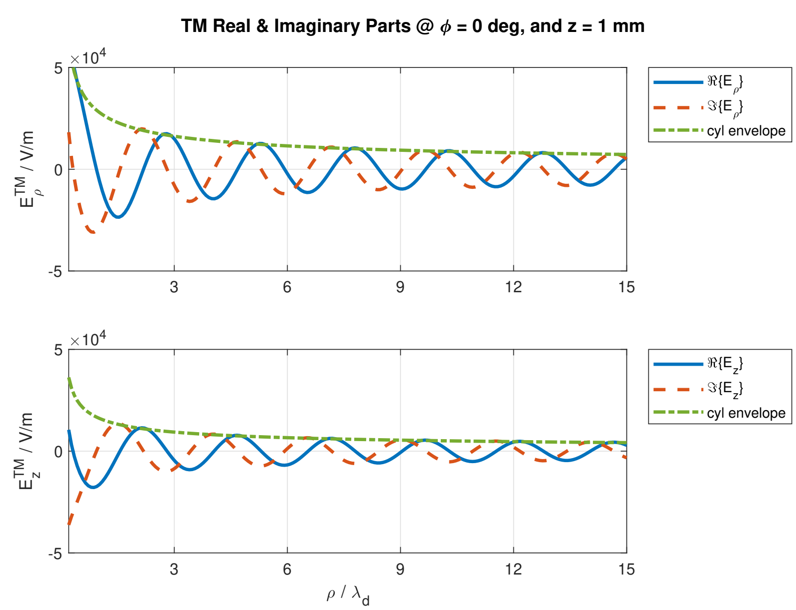

Fig. 3. Real and imaginary part of the TM0 surface wave components, for $f = 10$ GHz, as a function of the radial distance ρ inside the mid-point of the dielectric with $\epsilon_r = 10$ at $h = 1$ mm and $\phi = 0°$; the wave is excited by a half-wavelength dipole with width $W = 0.5$ mm and length $L = 15$ mm.

The variation in the amplitude of the TM0 surface wave components are plotted, at $\phi = 0°$ and $\rho = 15\lambda_d$, as a function of the elevation z in Fig.4 for $f = 10$ GHz and dielectric with permittivity $\epsilon_r = 10$; the interface boundary is shown at $z = 2$ mm. The surface waves are evanescent in the free space medium. Therefore, the amplitude of the components decreases exponentially with z after the dielectric to free space interface. The evanescence nature of the waves is observed on the plot. Moreover, the E_z^{TM0} component is zero due to the choice of ϕ and ρ.

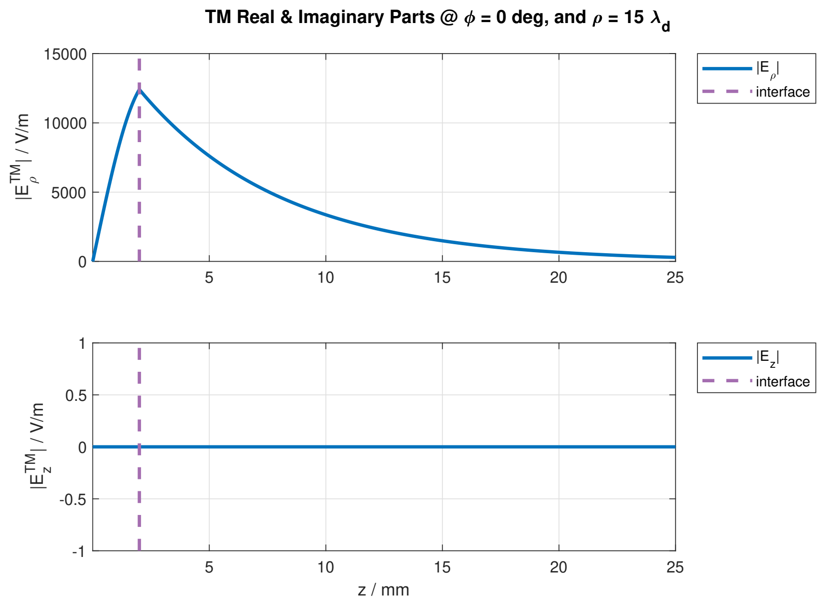

Fig. 4. Amplitude variation of the TM0 surface wave components, for $f = 10$ GHz, as a function of the elevation z at a radial distance of $\rho = 15\lambda_d$ and $\phi = 0°$; the dielectric has a permittivity $\epsilon_r = 10$, and the wave is excited by a half-wavelength dipole with width $W = 0.5$ mm and length $L = 15$ mm.

The variation in the amplitude of the TM0 surface wave components are plotted, at $\rho = 15\lambda_d$ and $h = 1$ mm, as a function of the azimuth angle ϕ in Fig.5[1] for $f = 10$ GHz and dielectric with permittivity $\epsilon_r = 10$. At $\phi = 90°$ and $\phi = 270°$, the components of the TM0 wave go to zero, because the mode is propagating parallel to the neighbourhood of the planes at which the source is oriented (in this case $\phi = 0$). On the other hand, the TE1 mode is propagating in the planes orthogonal to the source's orientation.

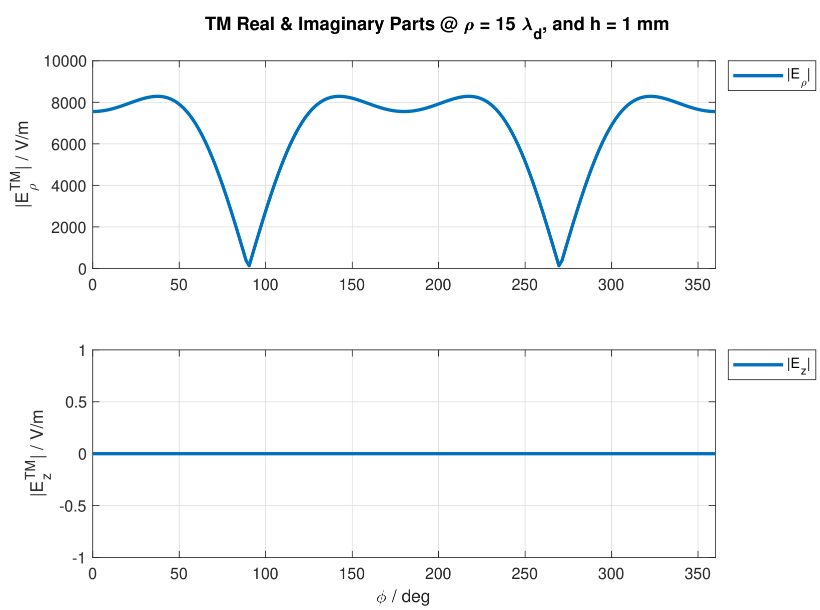

Fig. 5. Amplitude variation of the TM0 surface wave components, for $f = 10$ GHz, as a function of the azimuth angle ϕ at a radial distance of $\rho = 15\lambda_d$ inside the mid-point of the dielectric with $\epsilon_r = 10$ at $h = 1$ mm; the wave is excited by a half-wavelength dipole with width $W = 0.5$ mm and length $L = 15$ mm.

[1]Other plots plotting the amplitude, real, and imaginary parts of the TM0 surface wave as functions of ρ, z, and ϕ, are provided in Appendix.A

IV. Radiated and Surface Wave Power

The normalized radiated and surface wave power, to the power radiated by the same source in free space, from an elementary dipole are plotted as a function of the frequency (expressed as a normalized dielectric's height to the wavelength in the dielectric) in Fig.6; the dielectric's height is $h = 2$ mm and its permittivity $\epsilon_r = 10$. As the dielectric's height becomes electrically larger more power is embedded in the surface wave. On the other hand, the radiated power experiences a peak at around $h/\lambda_d = 0.25$, as a consequence of the radiated wave, in the direction of the PEC and reflected back, being in-phase with the radiated wave towards free space. The same effect causes the peak in the surface wave power at the same point $h/\lambda_d = 0.25$.

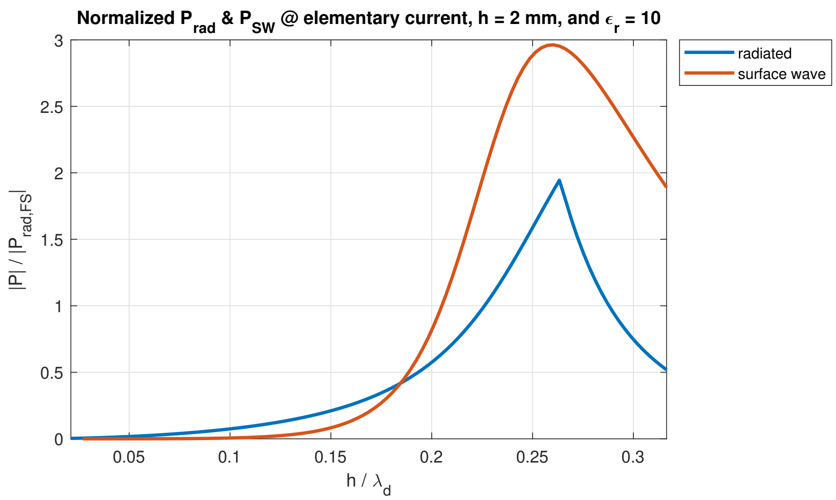

Fig. 6. Radiated and surface wave power from an elementary dipole on a grounded dielectric stratified media normalized to the power radiated by the same elementary dipole in free space, as a function of the dielectric's height in terms of the wavelength inside the dielectric; the dielectric has a height $h = 2$ mm and permittivity $e_r = 10$.

The surface wave efficiency of an elementary, dipole, and uniform current distributions are plotted in Fig.7 for a dielectric with height $h = 2$ mm and permittivity $\epsilon_r = 10$. The efficiency due to power embedded in the surface wave is

$$\eta_{SW} = \frac{P_{rad}}{P_{rad} + P_{SW}}. \tag{3}$$

Furthermore, as previously stated the power embedded in the surface waves increases with the electrical length of the dielectric. Consequently, less power is radiated while more power is embedded in the surface waves and the efficiency decreases. Moreover, at short electrical lengths, no modes are propagating and no power is embedded in the surface waves; therefore, the power is entirely radiated and the efficiency is 100 %. At around $h/\lambda_d = 0.25$, the radiated power has a peak, due to the in-phase addition, resulting in a peak at the efficiency. Finally, the power embedded by the elementary source is the most, followed by the dipole, and the uniform current distribution.

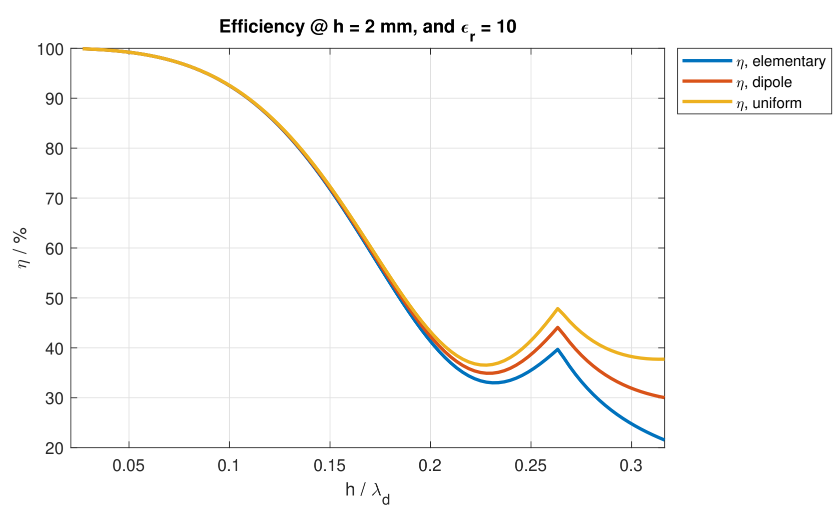

Fig. 7. Efficiency of an elementary dipole on a grounded dielectric stratified media due to the surface wave power loss for elementary current, dipole with length $L = 5.3$ mm and width $W = 0.5$ mm, and uniform current distribution with $L = W = 25$ mm, as a function of the dielectric's height in terms of the wavelength inside the dielectric; the dielectric has a height $h = 2$ mm and permittivity $e_r = 10$.

APPENDIX A
SURFACE WAVE PLOTS

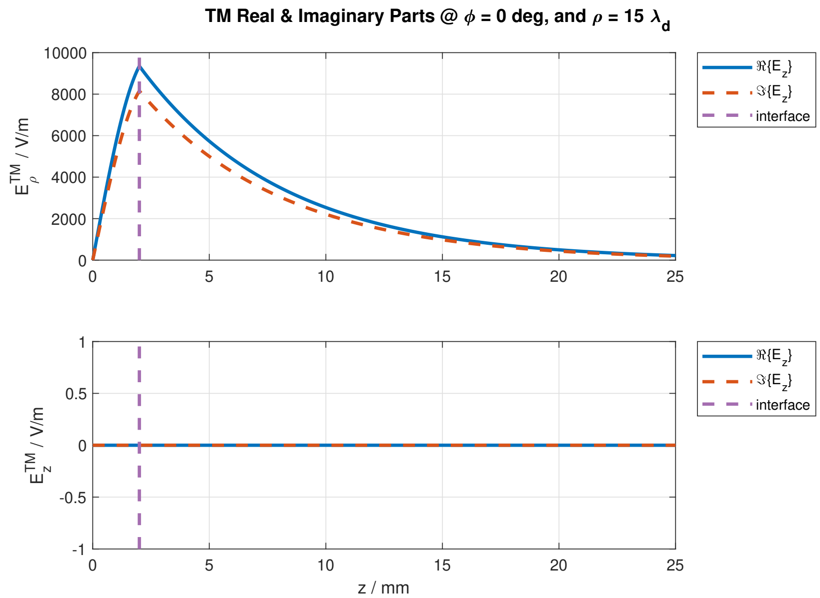

Fig. 8. Real and imaginary part of the TM0 surface wave components, for $f = 10$ GHz, as a function of the elevation z at a radial distance $\rho = 15\lambda_d$ and $\phi = 0°$; the dielectric has a permittivity $\epsilon_r = 10$, and the wave is excited by a half-wavelength dipole with width $W = 0.5$ mm and length $L = 15$ mm.

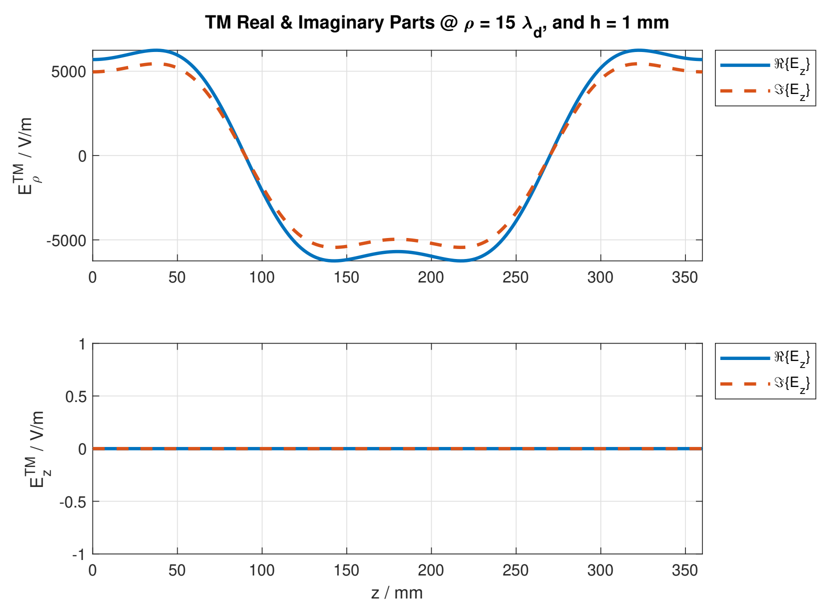

Fig. 9. Real and imaginary part of the TM0 surface wave components, for $f = 10$ GHz, as a function of the azimuth angle ϕ at a radial distance of $\rho = 15\lambda_d$ inside the mid-point of the dielectric with $\epsilon_r = 10$ at $h = 1$ mm; the wave is excited by a half-wavelength dipole with width $W = 0.5$ mm and length $L = 15$ mm.

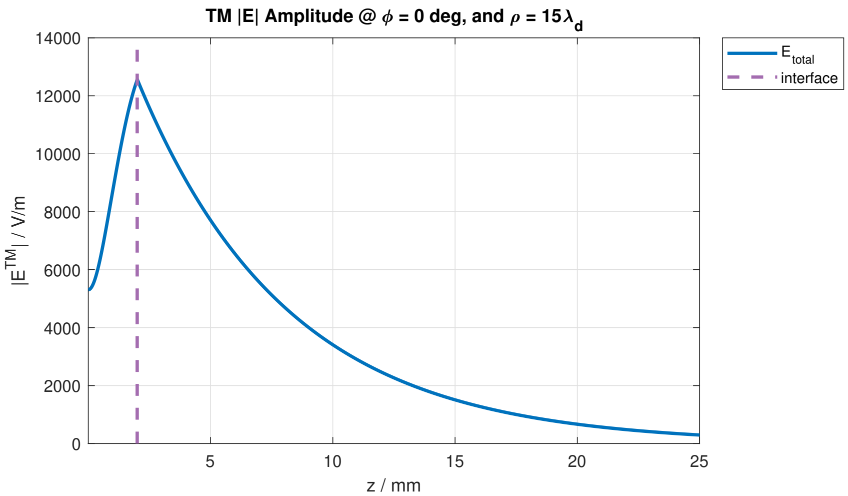

Fig. 10. Total field of the TM0 surface wave, for $f = 10$ GHz, as a function of the elevation z at a radial distance $\rho = 15\lambda_d$ and $\phi = 0°$; the dielectric has a permittivity $\epsilon_r = 10$, and the wave is excited by a half-wavelength dipole with width $W = 0.5$ mm and length $L = 15$ mm.

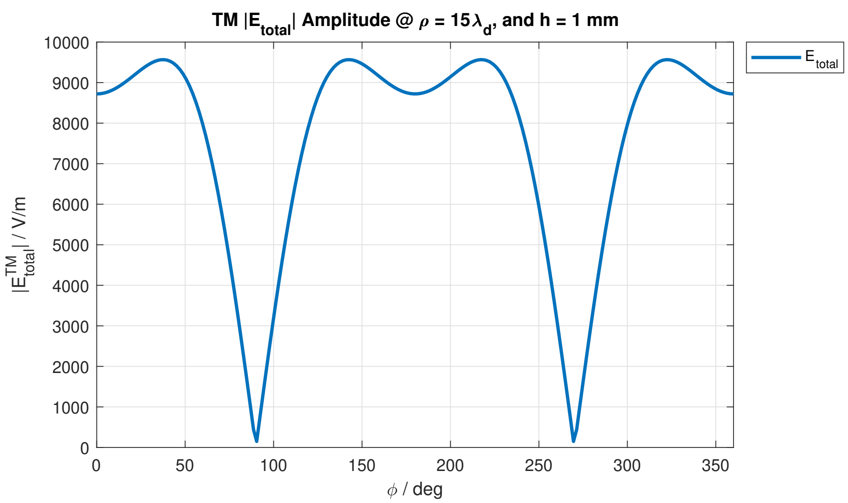

Fig. 11. Total field of the TM0 surface wave, for $f = 10$ GHz, as a function of the azimuth angle ϕ at a radial distance of $\rho = 15\lambda_d$ inside the mid-point of the dielectric with $\epsilon_r = 10$ at $h = 1$ mm; the wave is excited by a half-wavelength dipole with width $W = 0.5$ mm and length $L = 15$ mm.