Planar PCB Antenna of Two Dipoles

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EE4620 Spectral Domain Methods in Electromagnetics

TUDelft

Table of Contents

- Solutions of grounded substrate
- Substrate permittivity & height
  - Surface wave modes
  - Surface wave power
  - Reference with higher permittivity dielectric
- Minimization of surface waves
- Slots below substrate
- Cancellation of surface waves in slots

Grounded Substrate

- Free space solution

$$V_0(z) = \frac{Z_0 Z_{down}}{Z_0 + Z_{down}} e^{jk_{z0}h} e^{-jk_{z0}z}$$

$$I_0(z) = \frac{1}{Z_0} \frac{Z_0 Z_{down}}{Z_0 + Z_{down}} e^{jk_{z0}h} e^{-jk_{z0}z}$$

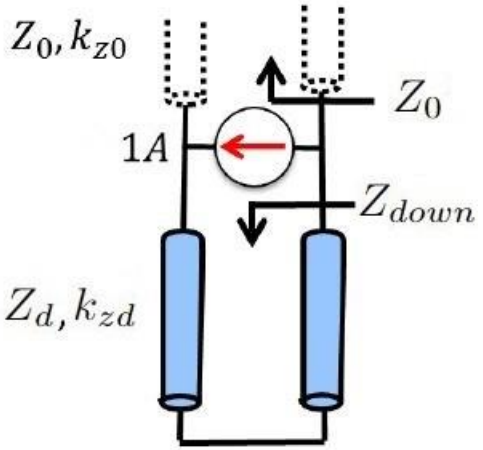
- Substrate solution

$$V_s(z) = \frac{Z_0 Z_{down}}{Z_0 + Z_{down}} \frac{\sin(k_{zd}z)}{\sin(k_{zd}h)}$$

$$I_s(z) = \frac{1}{Z_{down}} \frac{Z_0 Z_{down}}{Z_0 + Z_d} \frac{j\cos(k_{zd}z)}{\sin(k_{zd}h)}$$

- Dispersion equation

$$D(k_\rho) = Z_0 + Z_{down} = Z_0 + jZ_d \tan(k_{zd}h)$$



EE4620 Spectral Methods in Electromagnetics: Spectral Green's Function for Stratified Media MATLAB Instruction 1, Prof. Shahab Dabironezare, 3rd May 2023

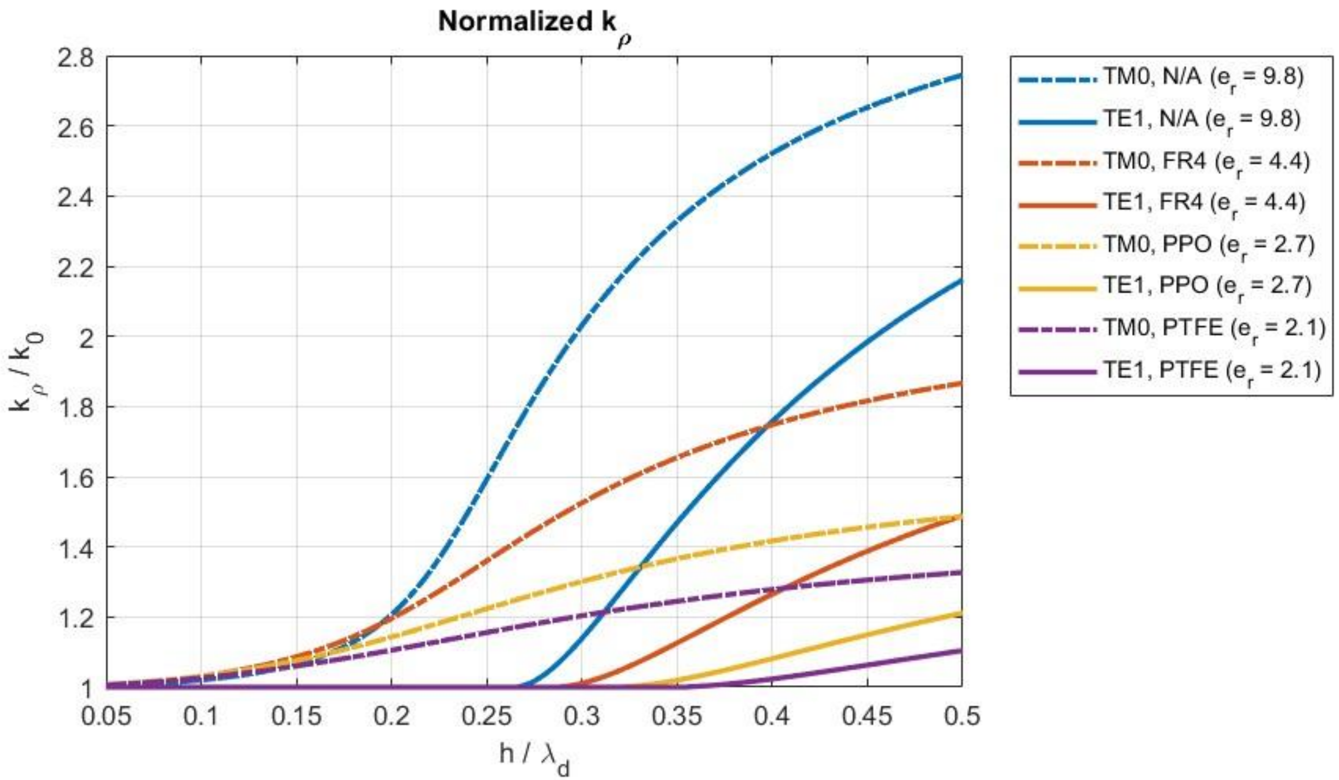
Surface Wave Modes

- For TM0 and TE1 modes

$$D(k_{\rho,i}) = Z_0^i + jZ_d^i \tan(k_{zd}h) = 0$$

- TE1 starts propagating at around

$$h/\lambda_d = 0.25$$



Surface Wave Power (1)

- For TM0 surface wave power

$$P_{SW}^{TM} = \frac{1}{2}\frac{k_{\rho,i}^2}{2\pi}\frac{\eta}{k}\int_0^{\infty} |Res\{i_{TM}(k_{\rho,i}, z, z')\}|^2 dz \int_0^{2\pi} |J_x(k_{\rho,i}, \phi)|^2 \cos^2(\phi) d\phi$$

- For TE1 surface wave power

$$P_{SW}^{TE} = \frac{1}{2}\frac{k_{\rho,i}^2}{2\pi}\frac{1}{\eta k}\int_0^{\infty} |Res\{v_{TE}(k_{\rho,i}, z, z')\}|^2 dz \int_0^{2\pi} |J_x(k_{\rho,i}, \phi)|^2 \sin^2(\phi) d\phi$$

- **Expectation:** Higher substrate

permittivity decreases the front-to-back ratio

and results in more power added to the

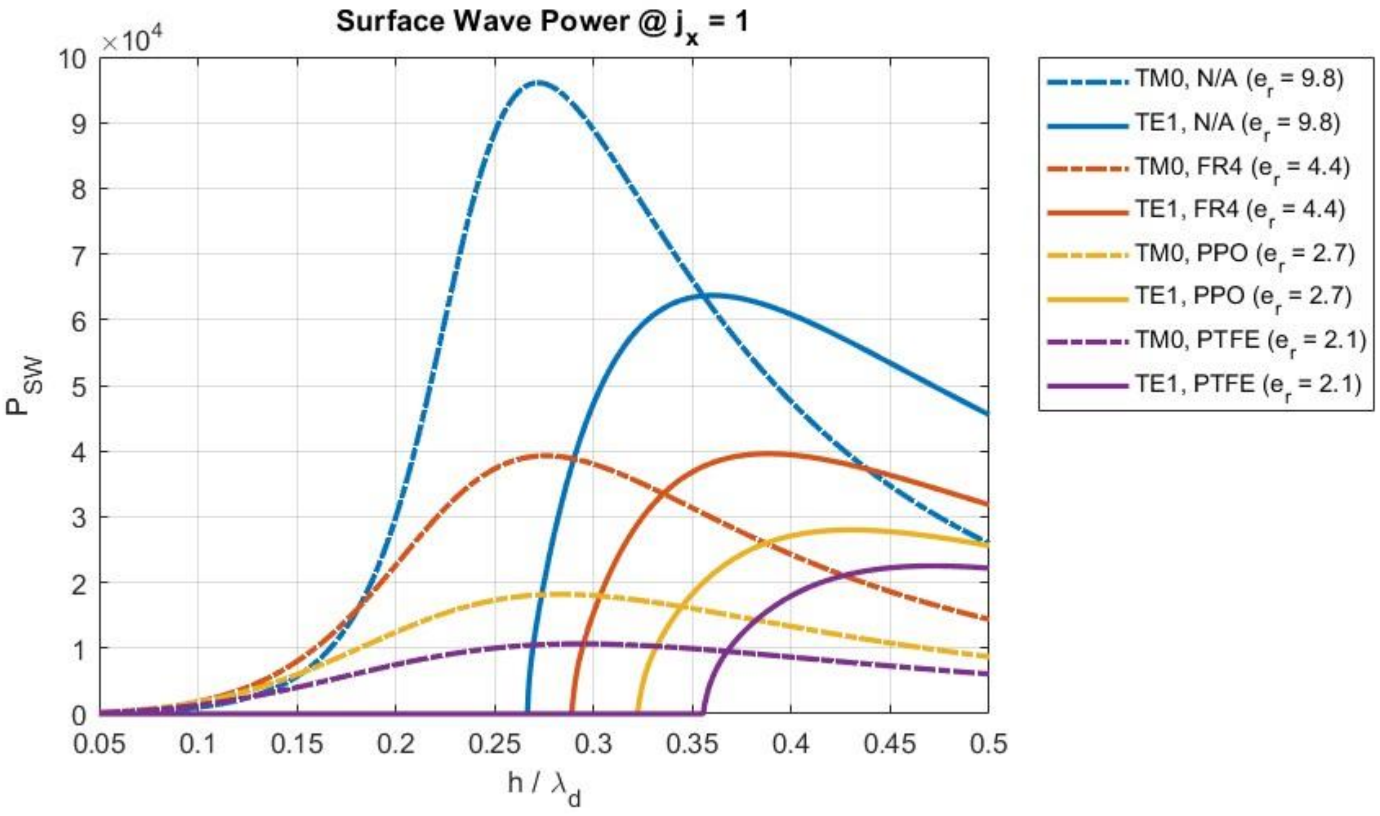
surface wave (higher substrate permittivity higher losses)

Surface Wave Power (2)

- Elementary current source

  $\vec{j} = 1\hat{x}$

- Higher permittivity results in more power in surface waves
- At low substrate height $h/\lambda_d \leq 0.15$, surface wave power is minimum; however, there is limitation in the bandwidth (dipole is close to the ground plane)
- At low substrate height $h/\lambda_d = 0.25$, larger bandwidth, no TE1 mode, and highest radiated power; however, largest TM0 surface wave power

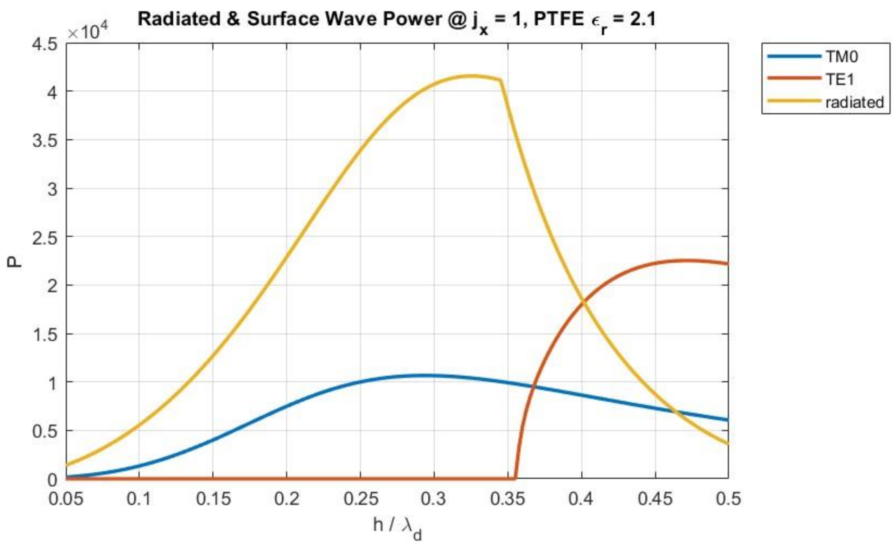


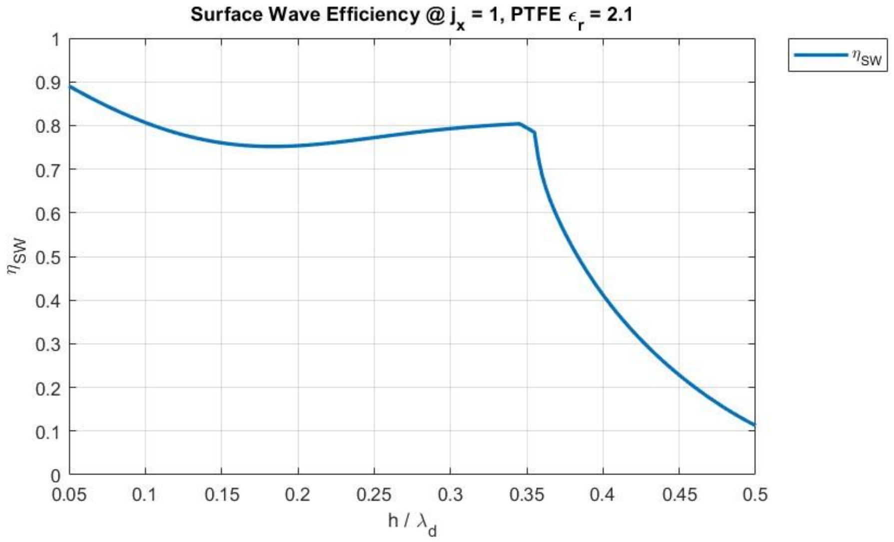
Substrate Permittivity & Height

- Dielectric with lowest permittivity is chosen to decrease the power in the surface waves (PTFE with $\varepsilon_r = 2.1$)

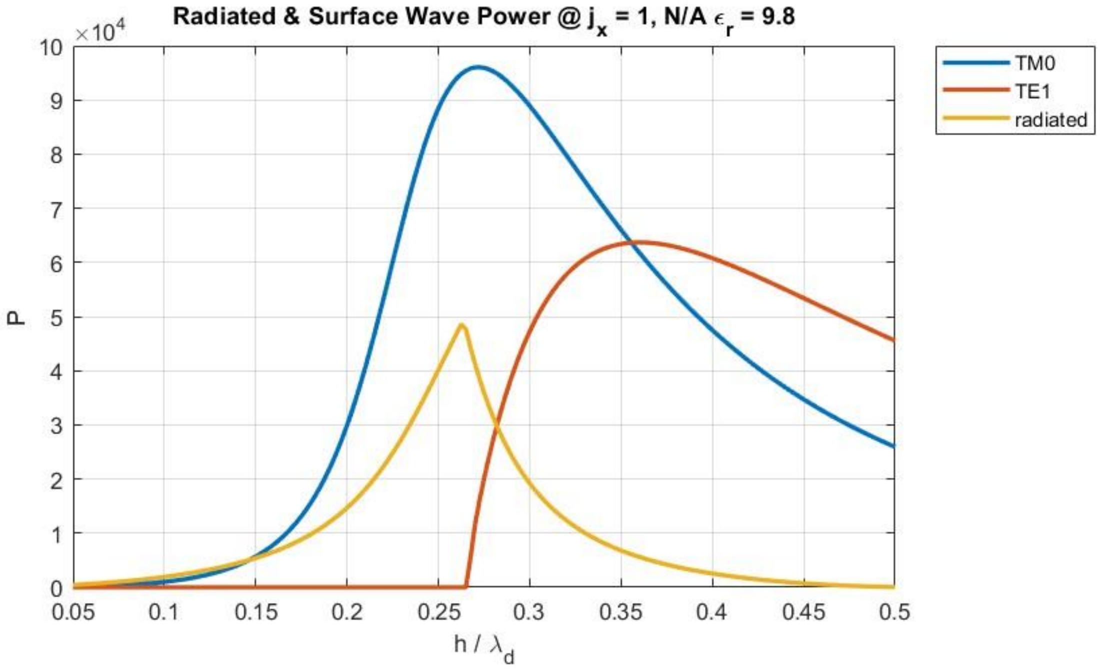
- To maximize the bandwidth and radiated power, while cutting-off the TE1 mode, the height is chosen at quarter-wavelength of dielectric ($\mathrm{h}/\lambda_d = 0.25$)

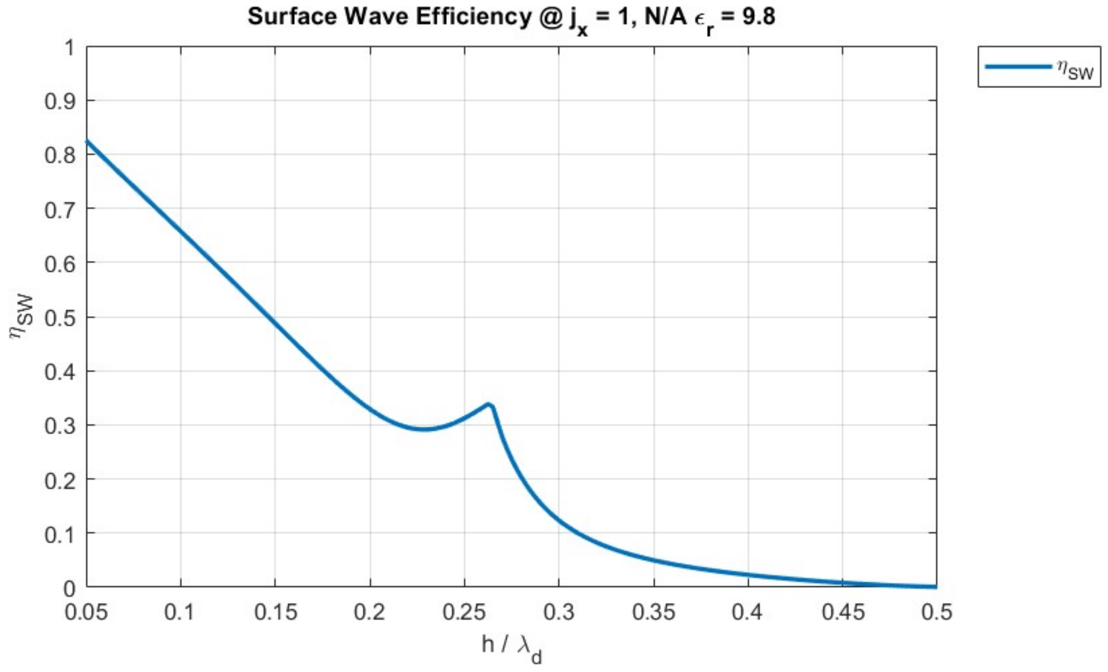
- At quarter-wavelength, the radiated and reflected wave from the ground plane add constructively, increasing the radiated power





Reference With Higher Permittivity





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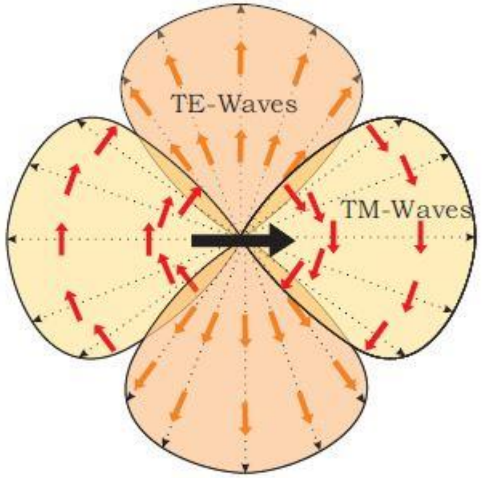
Surface Wave Minimization (1)

- For the chosen parameters, only TM0 surface wave propagates

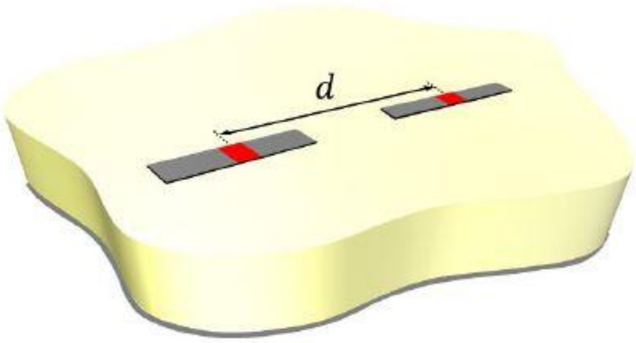
- TM0 surface wave propagates in $\phi = 0^{\circ}$ plane
- To minimize the power lost in the TM0 surface wave, the dipoles need to be on the same longitudinal axis

$$\vec{J}_1 + \vec{J}_2 = 2\frac{e^{jk_{x,sw}\frac{d}{2}} + e^{-jk_{x,sw}\frac{d}{2}}}{2}\hat{x} = 2\cos(k_{x,sw}\frac{d}{2})\hat{x}$$

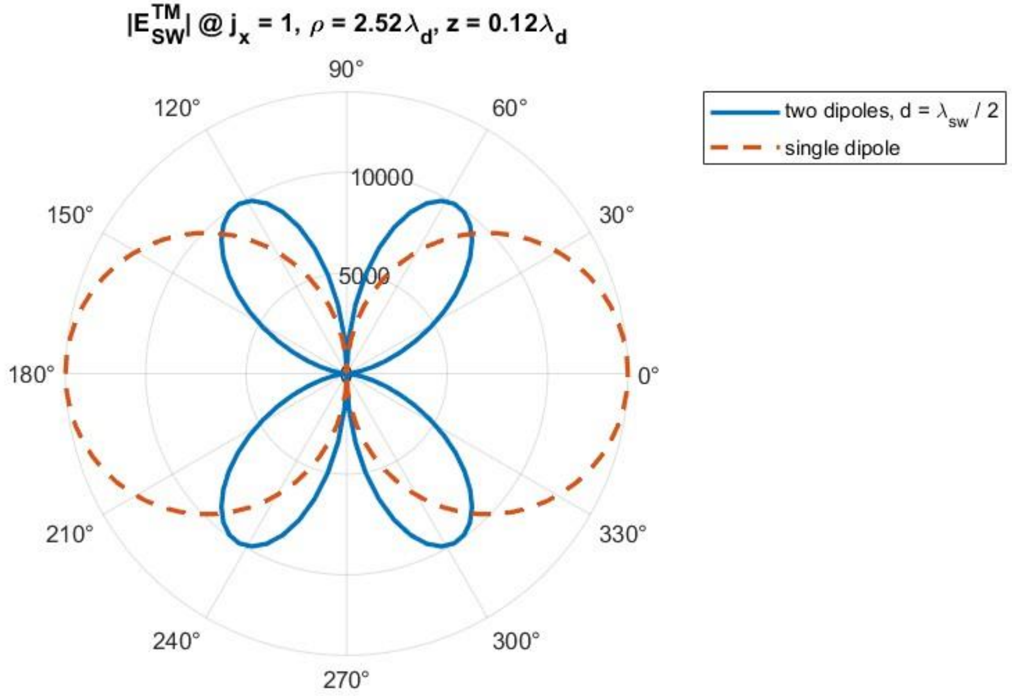
$$\cos(k_{x,sw}\frac{d}{2}) = 0, \quad k_{x,sw}\frac{d}{2} = \frac{\pi}{2}, \quad d = \frac{\pi}{k_{x,sw}}\,|_{k_{x,sw}=k_{\rho,sw}} = \frac{\lambda_{sw}}{2}$$

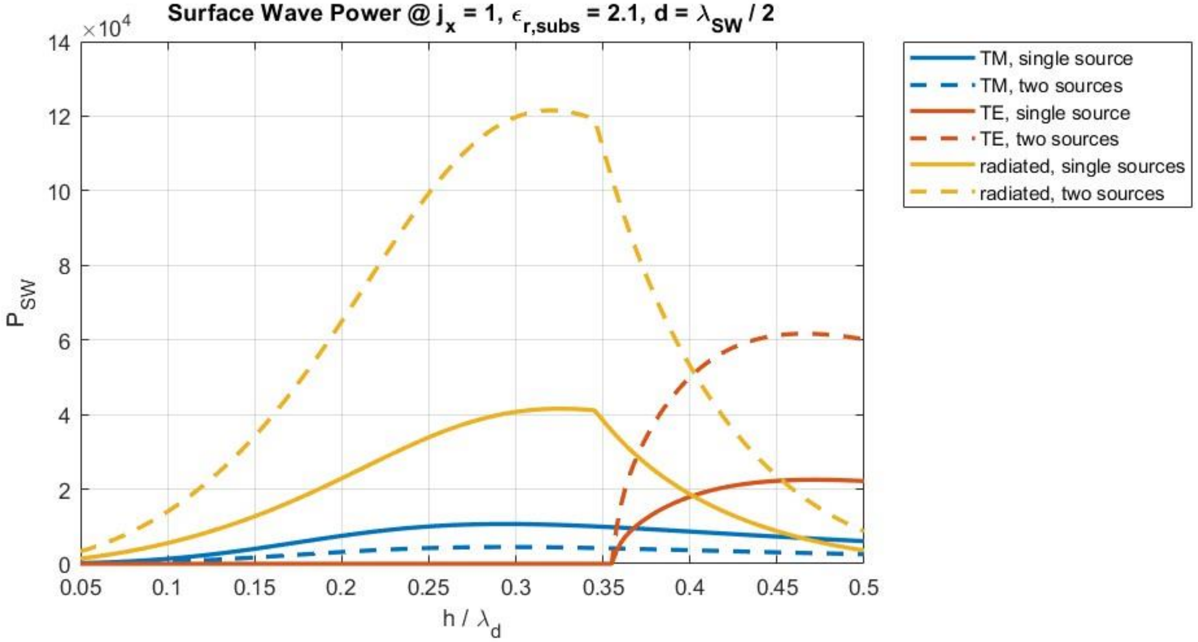


Characterization of Printed Transmission Lines at High Frequencies Using quasi-analytical expressions, M.Sc. Thesis, Sven van Berkel, 23rd April 2015



Surface Wave Minimization (2)





Slot Below Substrate (1)

- Free space solution

$$V_0(z) = \frac{1}{\Gamma_1 e^{-jk_{zd}h} + e^{jk_{zd}h}}(1+\Gamma_1)e^{jk_{z0}h}e^{-jk_{z0}z}$$

$$I_0(z) = \frac{1}{Z_0}\frac{1}{\Gamma_1 e^{-jk_{zd}h} + e^{jk_{zd}h}}(1+\Gamma_1)e^{jk_{z0}h}e^{-jk_{z0}z}$$

- Substrate solution

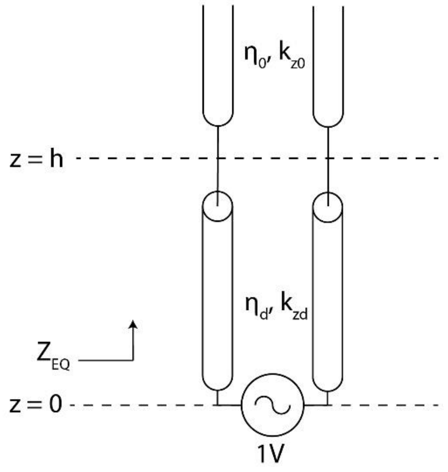
$$V_s(z) = \frac{e^{-jk_{zd}z}}{\Gamma_1 e^{-j2k_{zd}h} + 1}(1+\Gamma_1 e^{j2k_{zd}(z-h)})$$

$$I_s(z) = \frac{1}{Z_d}\frac{e^{-jk_{zd}z}}{\Gamma_1 e^{-j2k_{zd}h} + 1}(1-\Gamma_1 e^{j2k_{zd}(z-h)})$$

- Dispersion equation (same as for ground substrate)

$$Y_{eq} = Y_d \frac{Z_d + jZ_0 \tan(k_{zd}h)}{Z_0 + jZ_d \tan(k_{zd}h)}$$

$$D(k_{\rho,i}) = Z_0^i + jZ_d^i \tan(k_{zd}h)$$

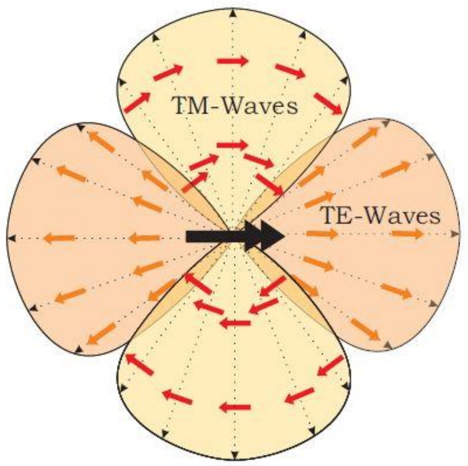


Slot Below Substrate (2)

- **Expectation:** Higher dielectric permittivity increases the front-to-back ratio, resulting in higher radiated power

- TM0 surface wave propagates in $\phi = 90^{\circ}$ plane
- To minimize the power lost in the TM0 surface wave, the slots need to be in on the same tangential axis

$$\cos(k_{y,sw}\frac{d}{2}) = 0, \quad k_{y,sw}\frac{d}{2} = \frac{\pi}{2}, \quad d = \frac{\pi}{k_{y,sw}}\Big|_{k_{y,sw}=k_{\rho,sw}} = \frac{\lambda_{sw}}{2}$$



Characterization of Printed Transmission Lines at High Frequencies Using quasi-analytical expressions, M.Sc. Thesis, Sven van Berkel, 23rd April 2015

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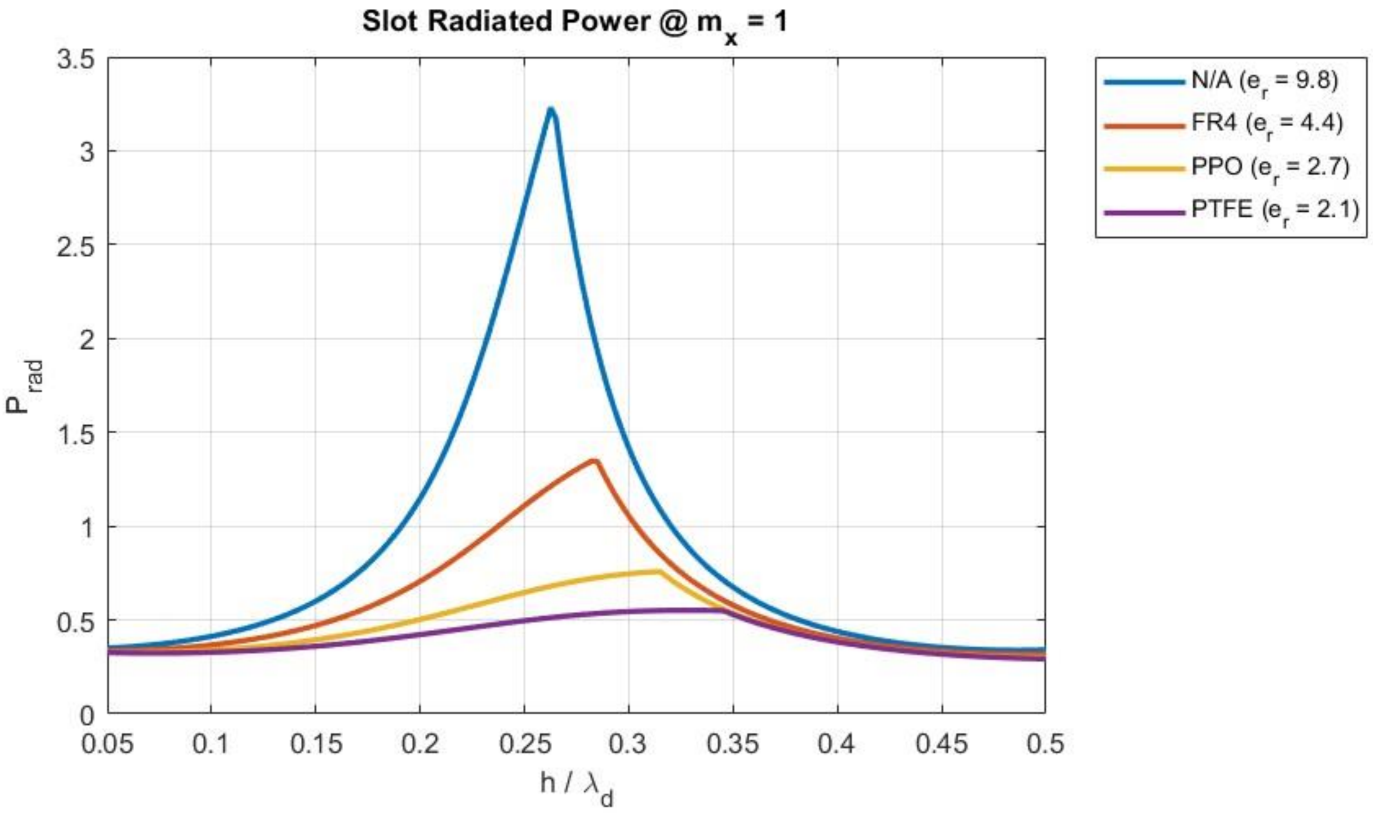
Slot Below Substrate (3)

- Higher permittivity results in higher front-to-back ratio and higher radiated power

- However, higher permittivity increases the losses in surface wave (reduces surface wave efficiency); these, surface wave must be minimized

- **Conclusion:** It is more convenient to use slots to increase the front-to-back ratio, when the surface waves are minimized / cancelled



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Slot Surface Wave Cancellation

- Double arc slot achieves full cancellation

of surface waves, but limits the bandwidth

- ADL has angle-dependent refractive

Index, it can be used to increase the

front-to-back ratio, while not allowing surface

waves to propagate; results in high bandwidth

and no surface waves

$$k_{zd}^{SW} = k_d \cos\theta_{SW}$$

$$n_{eff}^2 \,|_{\theta=\theta_{SW}} = 1$$

Q & A

Thank you for your attention

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