$$\frac{\beta}{k_o}E_x(i,j)=H_y(i,j)+\frac{j}{k_o\mathrm{dx}(i)}[E_z(i+1,j)-E_z(i,j)]\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega\epsilon_0\epsilon_{\mathrm{xx}}(i,j)}}\right)$$

$$\frac{\beta}{k_o}E_x(i,j)=H_y(i,j)+\frac{j}{k_o\mathrm{dx}(i)}\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega\epsilon_0\epsilon_{\mathrm{xx}}(i,j)}}\right)\left[\frac{-j}{k_o\mathrm{ddx}(i)\varepsilon_{\mathrm{zz}}(i+1,j)}[H_y(i+1,j)-H_y(i,j)]\left(\frac{1}{1-\frac{j\sigma_x(i+1)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i+1,j)}}\right)+\frac{j}{k_o\mathrm{ddy}(j-1)\varepsilon_{\mathrm{zz}}(i+1,j)}[H_x(i+1,j)-H_x(i+1,j-1)]\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i+1,j)}}\right)-\left(\frac{-j}{k_o\mathrm{ddx}(i-1)\varepsilon_{\mathrm{zz}}(i,j)}[H_y(i,j)-H_y(i-1,j)]\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j)}}\right)+\frac{j}{k_o\mathrm{ddy}(j-1)\varepsilon_{\mathrm{zz}}(i,j)}[H_x(i,j)-H_x(i,j-1)]\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j)}}\right)\right)\right]$$

$$\mathrm{ddx}(i)=\frac{\mathrm{dx}(i)+\mathrm{dx}(i+1)}{2}\qquad\mathrm{ddy}(j)=\frac{\mathrm{dy}(j)+\mathrm{dy}(j+1)}{2}$$

$$\epsilon'_{\mathrm{xx}}(i+1,j)=\frac{\epsilon_{\mathrm{xx}}(i+1,j)+\epsilon_{\mathrm{xx}}(i,j)}{2}\qquad\epsilon'_{\mathrm{yy}}(i,j+1)=\frac{\epsilon_{\mathrm{yy}}(i,j+1)+\epsilon_{\mathrm{yy}}(i,j)}{2}$$

$$\sigma_x=-\frac{(n+1)\epsilon_0c}{2\delta}\ln(R_{\mathrm{th}})\left(\frac{x}{\delta}\right)^n$$

$$\frac{\beta}{k_o}E_x(i,j)=H_y(i,j)+\frac{1}{k_o^2\mathrm{ddx}(i)\mathrm{dx}(i)\varepsilon_{\mathrm{zz}}(i+1,j)}[H_y(i+1,j)-H_y(i,j)]\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega\epsilon_0\epsilon_{\mathrm{xx}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_x(i+1)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i+1,j)}}\right)-\frac{1}{k_o^2\mathrm{dx}(i)\mathrm{ddy}(j-1)\varepsilon_{\mathrm{zz}}(i+1,j)}[H_x(i+1,j)-H_x(i+1,j-1)]\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega\epsilon_0\epsilon_{\mathrm{xx}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i+1,j)}}\right)-\frac{1}{k_o^2\mathrm{ddx}(i-1)\mathrm{dx}(i)\varepsilon_{\mathrm{zz}}(i,j)}[H_y(i,j)-H_y(i-1,j)]\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega\epsilon_0\epsilon_{\mathrm{xx}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j)}}\right)+\frac{1}{k_o^2\mathrm{dx}(i)\mathrm{ddy}(j-1)\varepsilon_{\mathrm{zz}}(i,j)}[H_x(i,j)-H_x(i,j-1)]\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega\epsilon_0\epsilon_{\mathrm{xx}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j)}}\right)$$

$$\frac{\beta}{k_o}E_y(i,j)=-H_x(i,j)+\frac{j}{k_o\mathrm{dy}(j)}[E_z(i,j+1)-E_z(i,j)]\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{w\epsilon_0\epsilon_{\mathrm{yy}}(i,j)}}\right)$$

$$\frac{\beta}{k_o}E_y(i,j)=-H_x(i,j)+\frac{j}{k_o\mathrm{dy}(j)}\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{w\epsilon_0\epsilon_{\mathrm{yy}}(i,j)}}\right)\left[\frac{-j}{k_o\mathrm{ddx}(i-1)\varepsilon_{\mathrm{zz}}(i,j+1)}[H_y(i,j+1)-H_y(i-1,j+1)]\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j+1)}}\right)+\frac{j}{k_o\mathrm{ddy}(j)\varepsilon_{\mathrm{zz}}(i,j)}[H_x(i,j+1)-H_x(i,j)]\left(\frac{1}{1-\frac{j\sigma_y(j+1)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j+1)}}\right)-\left(\frac{-j}{k_o\mathrm{ddx}(i-1)\varepsilon_{\mathrm{zz}}(i,j)}[H_y(i,j)-H_y(i-1,j)]\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j)}}\right)+\frac{j}{k_o\mathrm{ddy}(j-1)\varepsilon_{\mathrm{zz}}(i,j)}[H_x(i,j)-H_x(i,j-1)]\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j)}}\right)\right)\right]$$

$$\frac{\beta}{k_o}E_y(i,j)=-H_x(i,j)+\frac{1}{k_o^2\mathrm{dy}(j)\mathrm{ddx}(i-1)\varepsilon_{\mathrm{zz}}(i,j+1)}[H_y(i,j+1)-H_y(i-1,j+1)]\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{w\epsilon_0\epsilon_{\mathrm{yy}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j+1)}}\right)-\frac{1}{k_o^2\mathrm{dy}(j)\mathrm{ddy}(j)\varepsilon_{\mathrm{zz}}(i,j)}[H_x(i,j+1)-H_x(i,j)]\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{w\epsilon_0\epsilon_{\mathrm{yy}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j+1)}}\right)-\frac{1}{k_o^2\mathrm{dy}(j)\mathrm{ddx}(i-1)\varepsilon_{\mathrm{zz}}(i,j)}[H_y(i,j)-H_y(i-1,j)]\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{w\epsilon_0\epsilon_{\mathrm{yy}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j)}}\right)+\frac{1}{k_o^2\mathrm{dy}(j)\mathrm{ddy}(j-1)\varepsilon_{\mathrm{zz}}(i,j)}[H_x(i,j)-H_x(i,j-1)]\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{w\epsilon_0\epsilon_{\mathrm{yy}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j)}}\right)$$

Bu formüllerde şu normalizasyon uygulanmış:

$$H'=H\sqrt{\eta_0}\qquad E'=\frac{E}{\sqrt{\eta_0}}$$

$$\begin{aligned}
&\frac{\beta}{k_0}H_y(i,j)=\epsilon_{\mathrm{xx}}(i,j)E_x(i,j)+\frac{j}{k_0\mathrm{ddy}(j-1)}[H_z(i,j)-H_z(i,j-1)]\\
&\frac{\beta}{k_0}H_y(i,j)=\epsilon_{\mathrm{xx}}(i,j)E_x(i,j)+\frac{j}{k_0\mathrm{ddy}(j-1)}\left[\left(\frac{j}{k_0\mathrm{dx}(i)}[E_y(i+1,j)-E_y(i,j)]-\frac{j}{k_0\mathrm{dy}(j)}[E_x(i,j+1)-E_x(i,j)]\right)-\left(\frac{j}{k_0\mathrm{dx}(i)}[E_y(i+1,j-1)-E_y(i,j-1)]-\frac{j}{k_0\mathrm{dy}(j-1)}[E_x(i,j)-E_x(i,j-1)]\right)\right]\\
&\frac{\beta}{k_0}H_x(i,j)=-\epsilon_{\mathrm{yy}}(i,j)E_y(i,j)+\frac{j}{k_0\mathrm{ddx}(i-1)}[H_z(i,j)-H_z(i-1,j)]\\
&\frac{\beta}{k_0}H_x(i,j)=-\epsilon_{\mathrm{yy}}(i,j)E_y(i,j)+\frac{j}{k_0\mathrm{ddx}(i-1)}\left[\left(\frac{j}{k_0\mathrm{dx}(i)}[E_y(i+1,j)-E_y(i,j)]-\frac{j}{k_0\mathrm{dy}(j)}[E_x(i,j+1)-E_x(i,j)]\right)-\left(\frac{j}{k_0\mathrm{dx}(i-1)}[E_y(i,j)-E_y(i-1,j)]-\frac{j}{k_0\mathrm{dy}(j)}[E_x(i-1,j+1)-E_x(i-1,j)]\right)\right]
\end{aligned}$$

$$\frac{\beta}{k_0}H_y(i,j)=\epsilon_{\mathrm{xx}}(i,j)E_x(i,j)+\frac{j}{k_0\mathrm{ddy}(j-1)}[H_z(i,j)-H_z(i,j-1)]\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j)}}\right)$$

$$\frac{\beta}{k_0}H_y(i,j)=\epsilon_{\mathrm{xx}}(i,j)E_x(i,j)+\frac{j}{k_0\mathrm{ddy}(j-1)}\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j)}}\right)\left[\left(\frac{j}{k_0\mathrm{dx}(i)}[E_y(i+1,j)-E_y(i,j)]\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega_0\epsilon_0\epsilon_r(i,j)}}\right)-\frac{j}{k_0\mathrm{dy}(j)}[E_x(i,j+1)-E_x(i,j)]\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{\omega_0\epsilon_0\epsilon_r(i,j)}}\right)\right)-\left(\frac{j}{k_0\mathrm{dx}(i)}[E_y(i+1,j-1)-E_y(i,j-1)]\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega_0\epsilon_0\epsilon_r(i,j-1)}}\right)-\frac{j}{k_0\mathrm{dy}(j-1)}[E_x(i,j)-E_x(i,j-1)]\left(\frac{1}{1-\frac{j\sigma_y(j-1/2)}{\omega_0\epsilon_0\epsilon_r(i,j-1)}}\right)\right)\right]$$

$$\frac{\beta}{k_0}H_y(i,j)=\epsilon_{\mathrm{xx}}(i,j)E_x(i,j)+\frac{-1}{k_0^2\mathrm{dx}(i)\mathrm{ddy}(j-1)}[E_y(i+1,j)-E_y(i,j)]\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega_0\epsilon_0\epsilon_r(i,j)}}\right)+\frac{1}{k_0^2\mathrm{dy}(j)\mathrm{ddy}(j-1)}[E_x(i,j+1)-E_x(i,j)]\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{\omega_0\epsilon_0\epsilon_r(i,j)}}\right)+\frac{1}{k_0^2\mathrm{dx}(i)\mathrm{ddy}(j-1)}[E_y(i+1,j-1)-E_y(i,j-1)]\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega_0\epsilon_0\epsilon_r(i,j-1)}}\right)-\frac{1}{k_0^2\mathrm{dy}(j-1)\mathrm{ddy}(j-1)}[E_x(i,j)-E_x(i,j-1)]\left(\frac{1}{1-\frac{j\sigma_y(j)}{\omega\epsilon_0\epsilon'_{\mathrm{yy}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_y(j-1/2)}{\omega_0\epsilon_0\epsilon_r(i,j-1)}}\right)$$

$$\frac{\beta}{k_0}H_x(i,j)=-\epsilon_{\mathrm{yy}}(i,j)E_y(i,j)+\frac{j}{k_0\mathrm{ddx}(i-1)}[H_z(i,j)-H_z(i-1,j)]\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j)}}\right)$$

$$\frac{\beta}{k_0}H_x(i,j)=-\epsilon_{\mathrm{yy}}(i,j)E_y(i,j)+\frac{j}{k_0\mathrm{ddx}(i-1)}\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j)}}\right)\left[\left(\frac{j}{k_0\mathrm{dx}(i)}[E_y(i+1,j)-E_y(i,j)]\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega_0\epsilon_0\epsilon_r(i,j)}}\right)-\frac{j}{k_0\mathrm{dy}(j)}[E_x(i,j+1)-E_x(i,j)]\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{\omega_0\epsilon_0\epsilon_r(i,j)}}\right)\right)-\left(\frac{j}{k_0\mathrm{dx}(i-1)}[E_y(i,j)-E_y(i-1,j)]\left(\frac{1}{1-\frac{j\sigma_x(i-1/2)}{\omega_0\epsilon_0\epsilon_r(i-1,j)}}\right)-\frac{j}{k_0\mathrm{dy}(j)}[E_x(i-1,j+1)-E_x(i-1,j)]\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{\omega_0\epsilon_0\epsilon_r(i-1,j)}}\right)\right)\right]$$

$$\frac{\beta}{k_0}H_x(i,j)=-\epsilon_{\mathrm{yy}}(i,j)E_y(i,j)+\frac{-1}{k_0^2\mathrm{dx}(i)\mathrm{ddx}(i-1)}[E_y(i+1,j)-E_y(i,j)]\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_x(i+1/2)}{\omega_0\epsilon_0\epsilon_r(i,j)}}\right)+\frac{1}{k_0^2\mathrm{dy}(j)\mathrm{ddx}(i-1)}[E_x(i,j+1)-E_x(i,j)]\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{\omega_0\epsilon_0\epsilon_r(i,j)}}\right)+\frac{1}{k_0^2\mathrm{dx}(i-1)\mathrm{ddx}(i-1)}[E_y(i,j)-E_y(i-1,j)]\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_x(i-1/2)}{\omega_0\epsilon_0\epsilon_r(i-1,j)}}\right)-\frac{1}{k_0^2\mathrm{dy}(j)\mathrm{ddx}(i-1)}[E_x(i-1,j+1)-E_x(i-1,j)]\left(\frac{1}{1-\frac{j\sigma_x(i)}{\omega\epsilon_0\epsilon'_{\mathrm{xx}}(i,j)}}\right)\left(\frac{1}{1-\frac{j\sigma_y(j+1/2)}{\omega_0\epsilon_0\epsilon_r(i-1,j)}}\right)$$

$\epsilon'_{\mathrm{yy}}(j)=0.5(\epsilon_{\mathrm{yy}}(j)+\epsilon_{\mathrm{yy}}(j-1))$
$\sigma_y(j)=H_y(j)$ noktasındaki σ_y değeri

In fdfd_solve method, compact formulation is used which employs P,Q matrices instead of A and solves only for E vector. Then H vector is calculated from E vector.