

# FD-TD

## Finite-Difference Time-Domin

## Maxwell方程式の 直接解法

# Maxwellの方程式の一次元化

$$\mathit{rot}\mathbf{H} = \varepsilon \frac{\partial \mathbf{E}}{\partial t}$$

$$\frac{\partial E_x}{\partial t} = -\frac{1}{\varepsilon} \frac{\partial H_y}{\partial z}$$

$$\mathit{rot}\mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$

$$\frac{\partial H_y}{\partial t} = -\frac{1}{\mu} \frac{\partial H_x}{\partial z}$$

# 時間－空間の離散化

$$z = i \cdot \Delta z$$

$$t = n \cdot \Delta t$$

$$F^{(n)}(i) = F(z, t) = F(i \cdot \Delta z, n \cdot \Delta t)$$

# 空間の離散化と 電界・磁界のサンプル位置

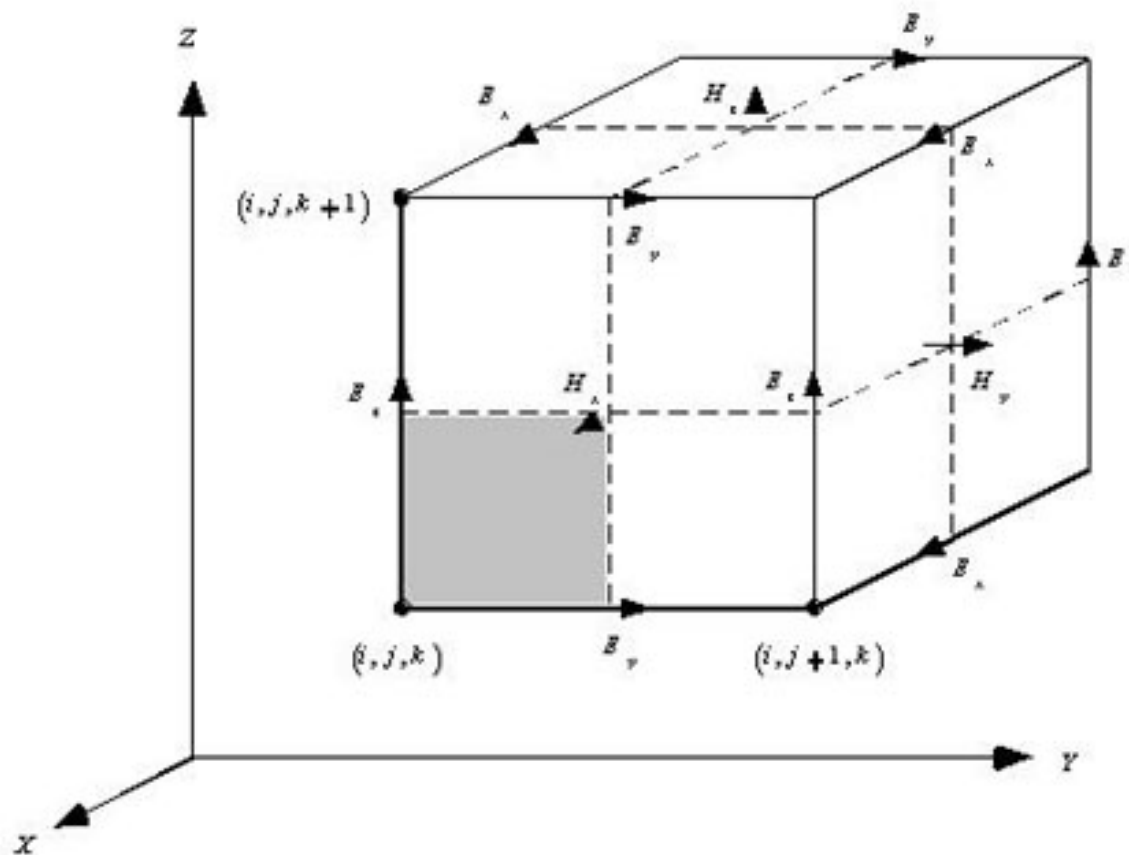


Figure 2-1: Yee's lattice for the FDTD method.

# 時間・空間微分の差分化

$$\frac{\partial E_x}{\partial t} = -\frac{1}{\varepsilon} \frac{\partial H_y}{\partial z}$$

$$\frac{E_x^{n+1}(i) - E_x^n(i)}{\Delta t} = -\frac{1}{\varepsilon(i)} \frac{H_y^{n+\frac{1}{2}}(i + \frac{1}{2}) - H_y^{n+\frac{1}{2}}(i - \frac{1}{2})}{\Delta z}$$

$$E_x^{n+1}(i) = E_x^n(i) - \frac{\Delta t}{\Delta z \varepsilon(i)} \left[ H_y^{n+\frac{1}{2}}(i + \frac{1}{2}) - H_y^{n+\frac{1}{2}}(i - \frac{1}{2}) \right]$$

# 差分化されたMaxwellの方程式

$$\frac{\partial E_x}{\partial t} = -\frac{1}{\varepsilon} \frac{\partial H_y}{\partial z}$$

$$\frac{\partial H_y}{\partial t} = -\frac{1}{\mu} \frac{\partial H_x}{\partial z}$$

$$E_x^{n+1}(i) = E_x^n(i) - \frac{\Delta t}{\Delta z \varepsilon(i)} \left[ H_y^{n+\frac{1}{2}}\left(i + \frac{1}{2}\right) - H_y^{n+\frac{1}{2}}\left(i - \frac{1}{2}\right) \right]$$

$$H_y^{n+\frac{1}{2}}\left(i + \frac{1}{2}\right) = H_y^{n-\frac{1}{2}}\left(i + \frac{1}{2}\right) - \frac{\Delta t}{\Delta z \mu(i)} \left[ E_x^n(i+1) - E_x^n(i) \right]$$

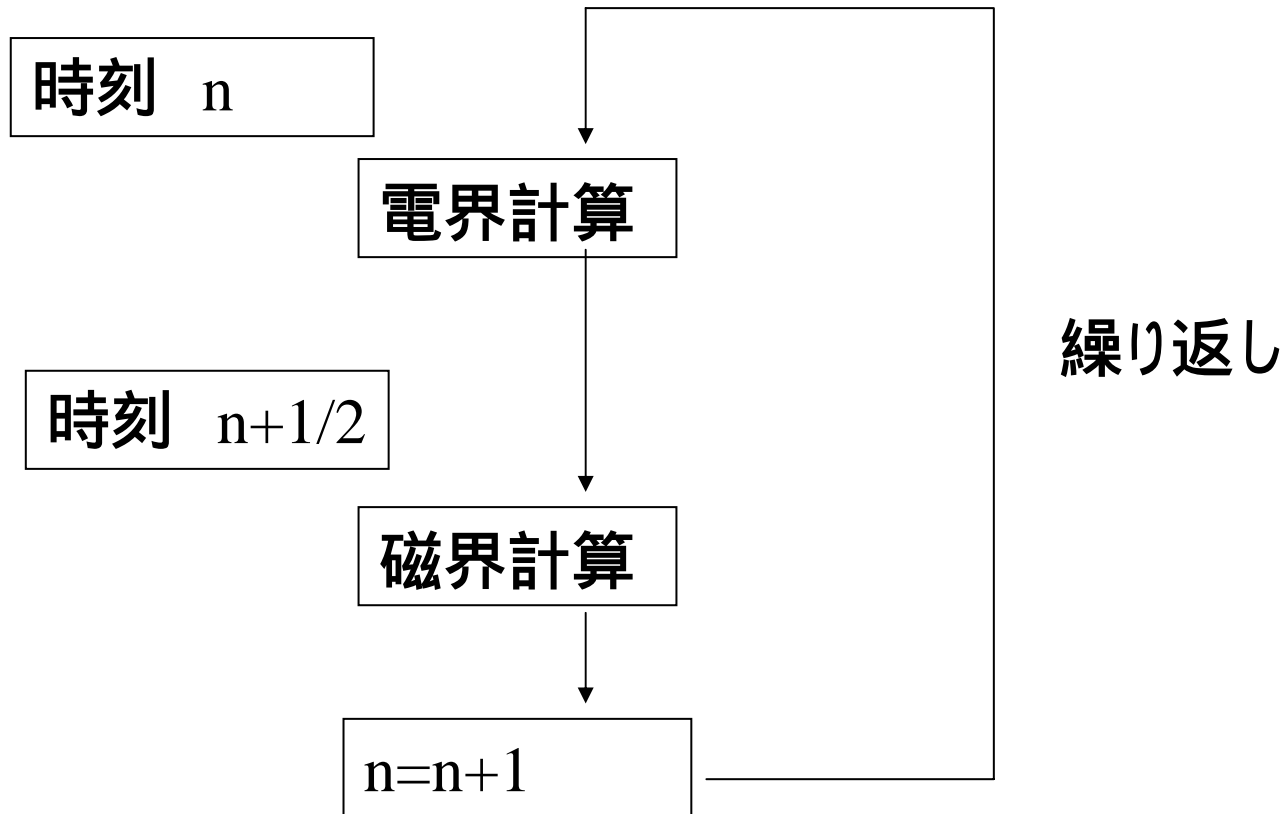
# 電磁界を計算のアルゴリズム

$$E_x^{n+1}(i) = E_x^n(i) - \frac{\Delta t}{\Delta z \epsilon(i)} \left[ H_y^{n+\frac{1}{2}}(i + \frac{1}{2}) - H_y^{n+\frac{1}{2}}(i - \frac{1}{2}) \right]$$

$$H_y^{n+\frac{1}{2}}(i + \frac{1}{2}) = H_y^{n-\frac{1}{2}}(i + \frac{1}{2}) - \frac{\Delta t}{\Delta z \mu(i)} \left[ E_x^n(i + 1) - E_x^n(i) \right]$$

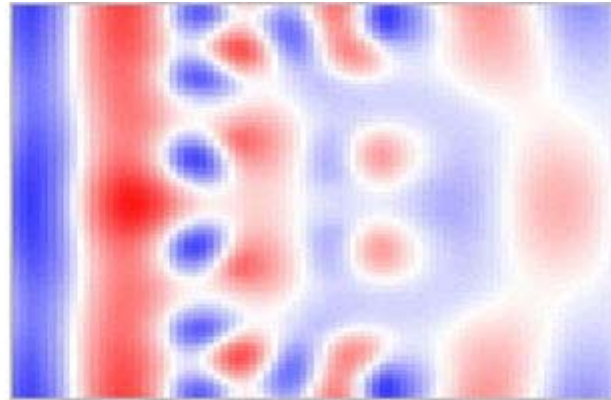
- 常に以前の時間における電磁界を使って未来の電磁界を計算する。
- 空間のパラメータ(導電率、誘電率)を容易に組み込める

# FDTD計算アルゴリズム

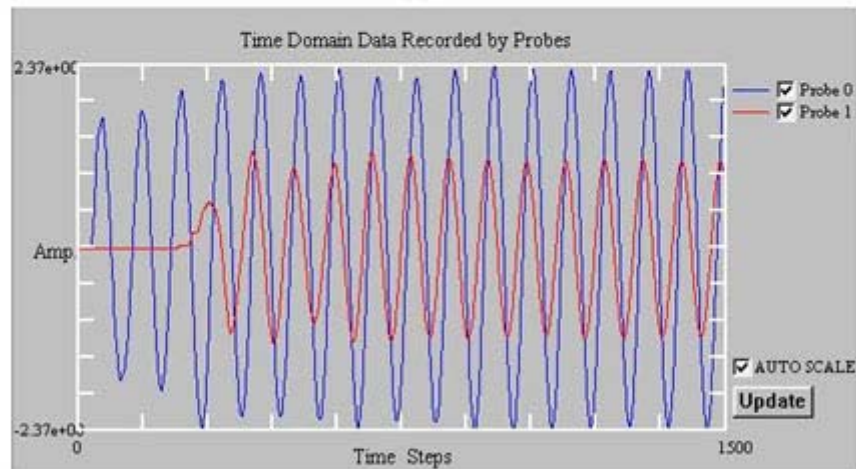




# シミュレーション

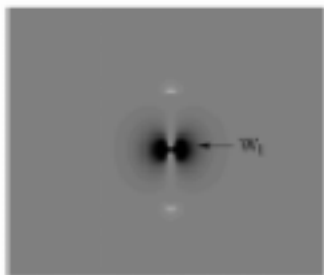


(a)

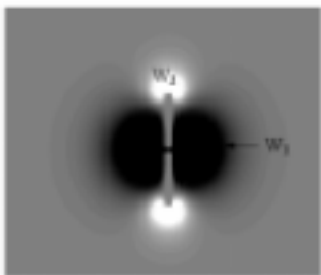


(b)

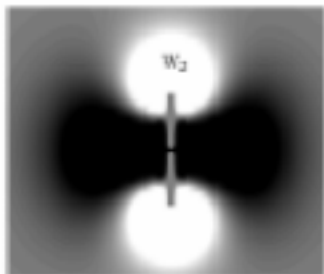
Figure 4-4: Field distribution (a) and time-domain data (b) with 11.14GHz sinusoidal excitation after 1500 time steps.



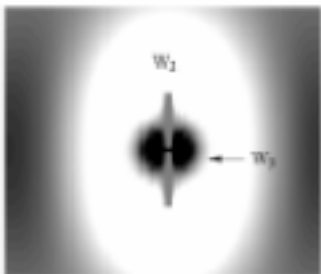
(a)



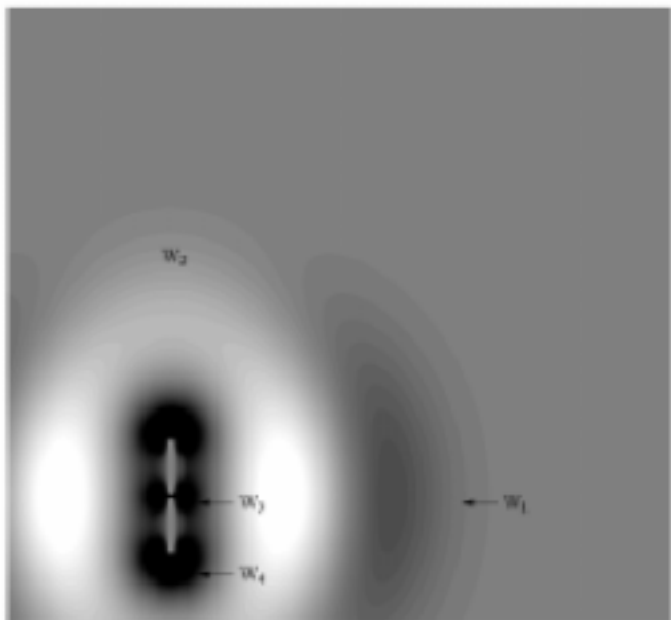
(b)



(c)

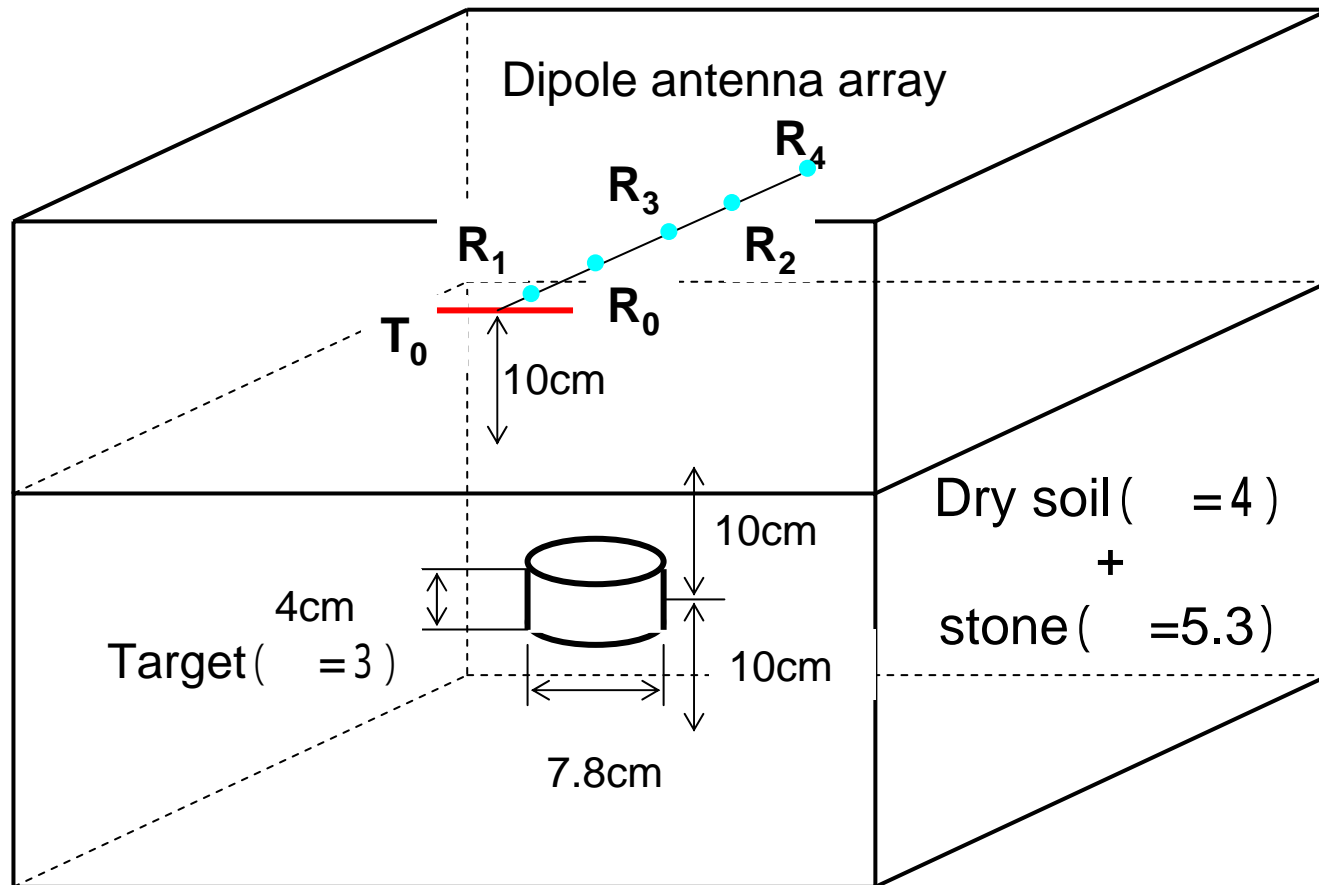


(d)

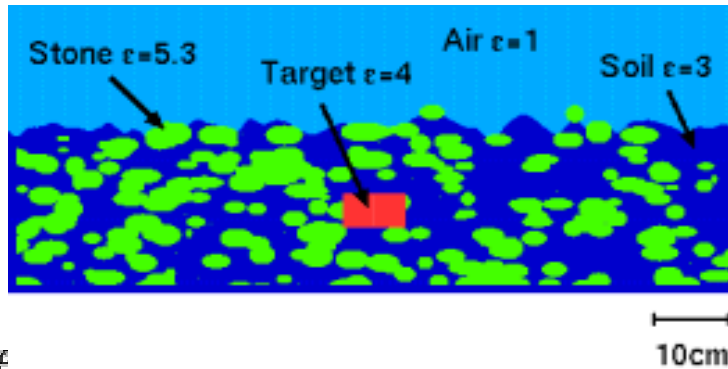


# ダイポールアンテナから放射される電磁波

# 不均質土壌中の地雷検知モデル



# FDTD による不均質な土壌中の地雷検知シミュレーション



Gaussian rough surface.  
RMS height = 15mm,  
Correlation distance = 20mm.

