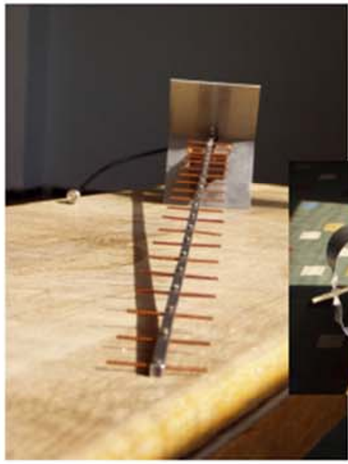
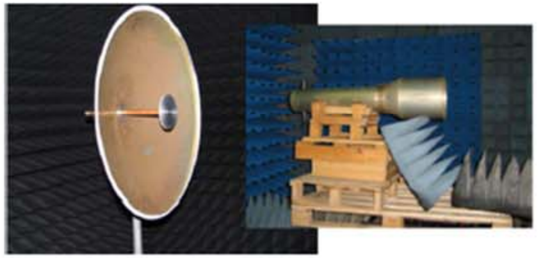
# Antenna Basics 3

# The “antenna family”

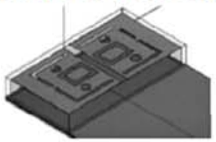
- **Wire antennas**
- Straight wire (dipole), loop, helix, …

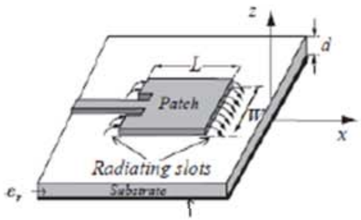




- **Aperture antennas**
- Horns, reflectors, lens



- **Planar (“microstrip” antennas)**
- Metallic patch on a grounded substrate

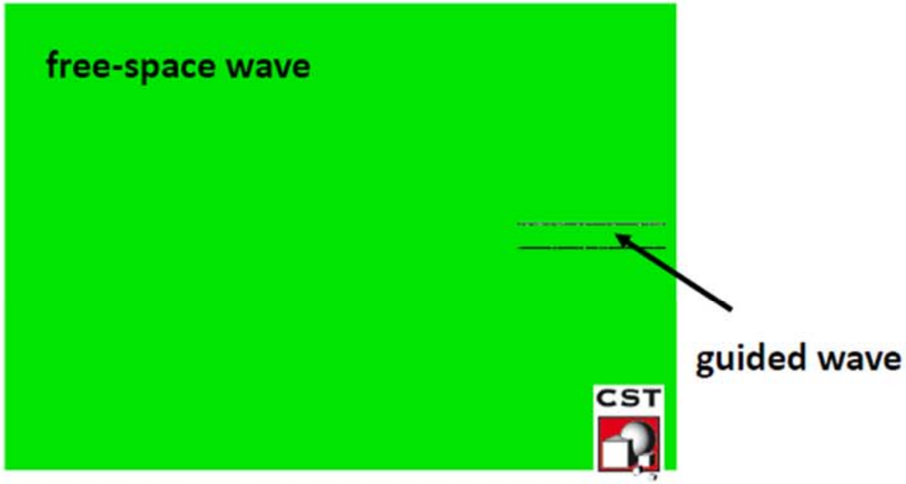


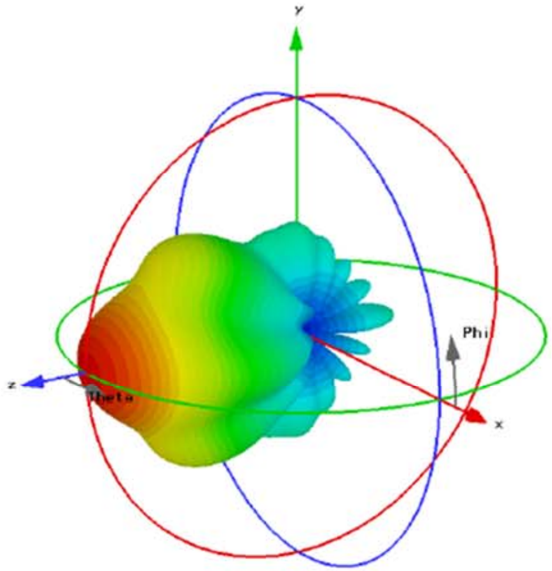



- **“Special” antennas**
- fractal geometry, on-chip antennas, mm-wave antennas, metamaterials, antennas for medical applications (implantable)…

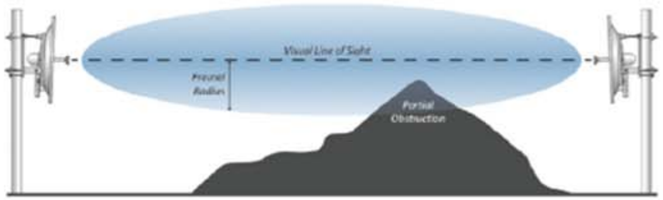
# Antenna is…

- Passive filter, both in frequency and spatial domain
- Component transforming guided waves to waves in free space (that is actually 3D spherical waveguide)
- Very important component of the whole communication channel
- „The best amplifier“



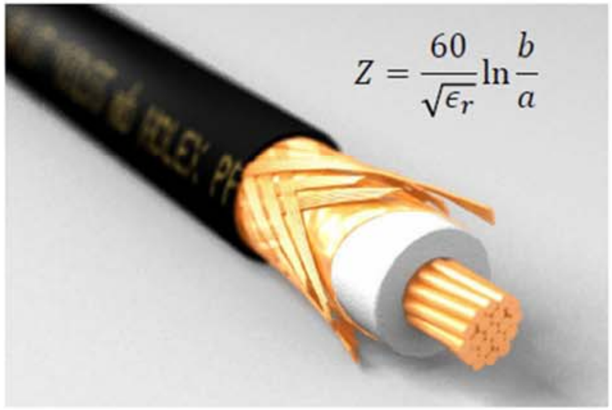



# Antenna link – the low loss link



# Waveguides

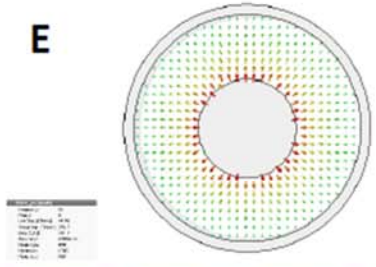
- With TEM wave (operation from DC): coaxial cable, multiconductor line
- Parameters not function of frequency! (no dispersion)



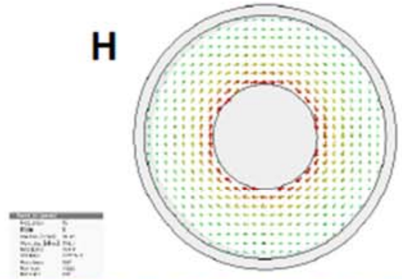
$$Z = \frac{60}{\sqrt{\epsilon_r}} \ln \frac{b}{a}$$

**TEM**

**E**



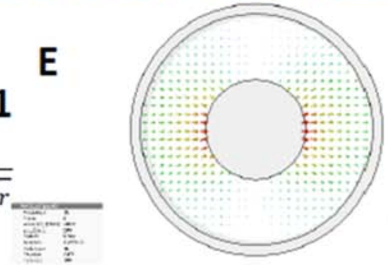
**H**



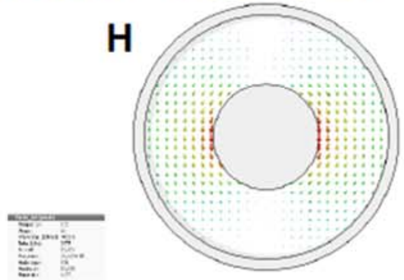
**Quasi-TE11**

$$f_c \cong \frac{c_0}{\pi(a+b)\sqrt{\epsilon_r}}$$

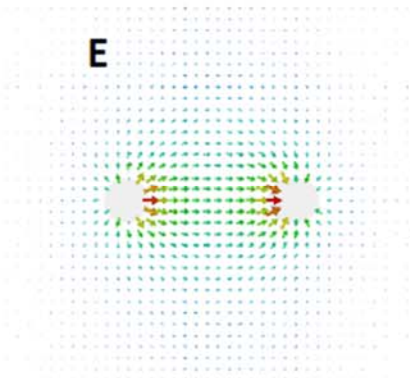
**E**



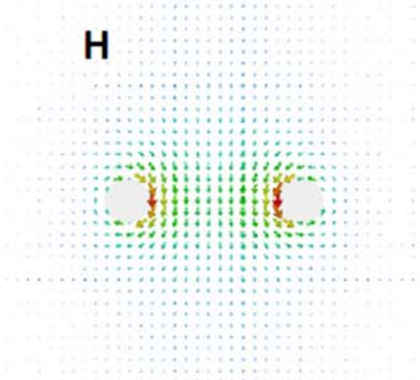
**H**



**E**



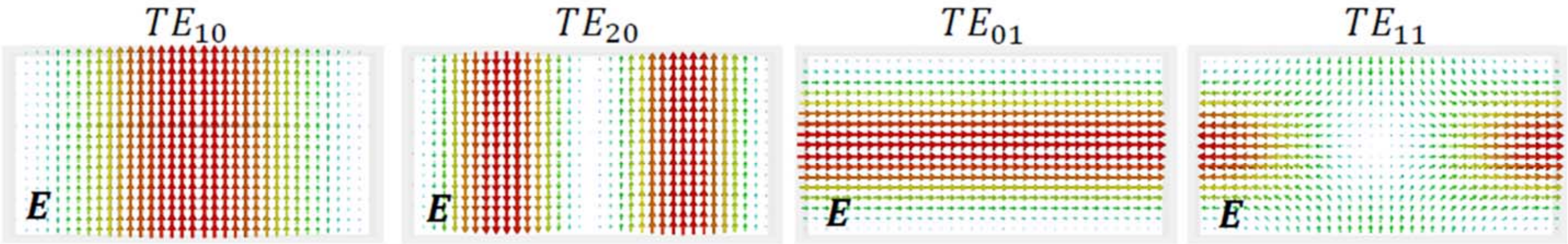
**H**

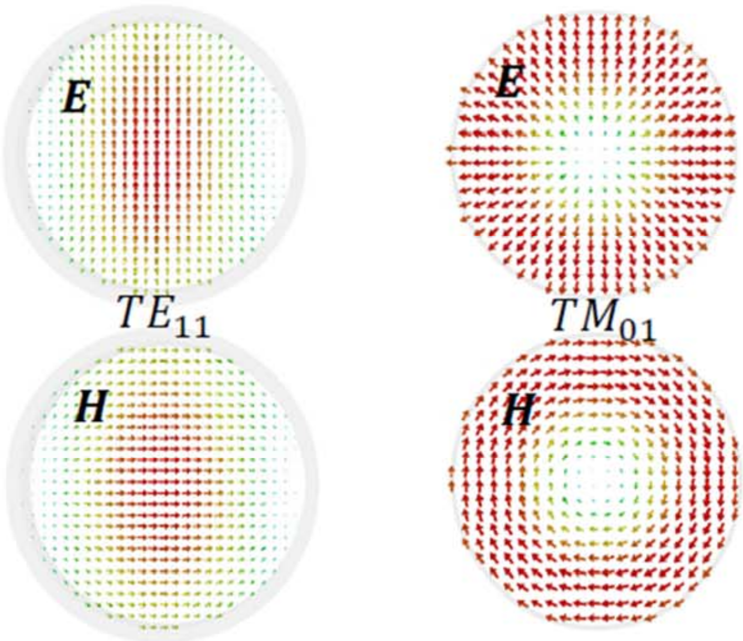


$$Z = \frac{120}{\sqrt{\epsilon_r}} \cosh^{-1}\left(\frac{D}{d}\right)$$

# Waveguides - metallic

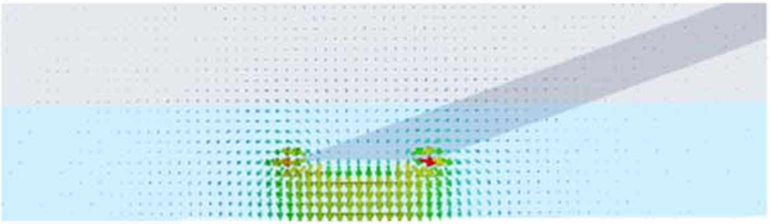
- With TE/TM modes (operation above cut-off frequency): metallic waveguides
- Parameters are function of frequency! (dispersion)

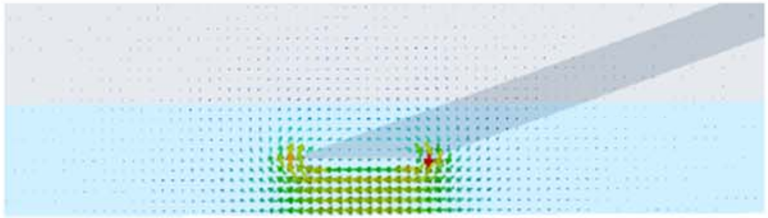


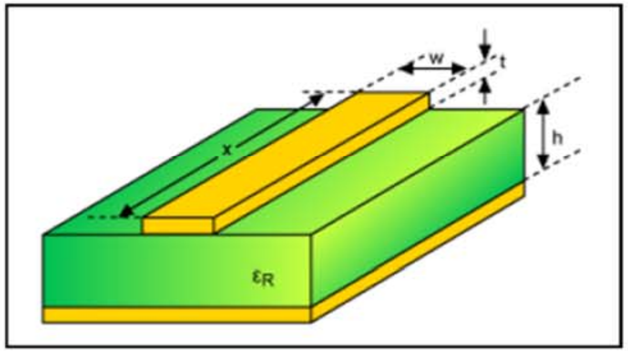



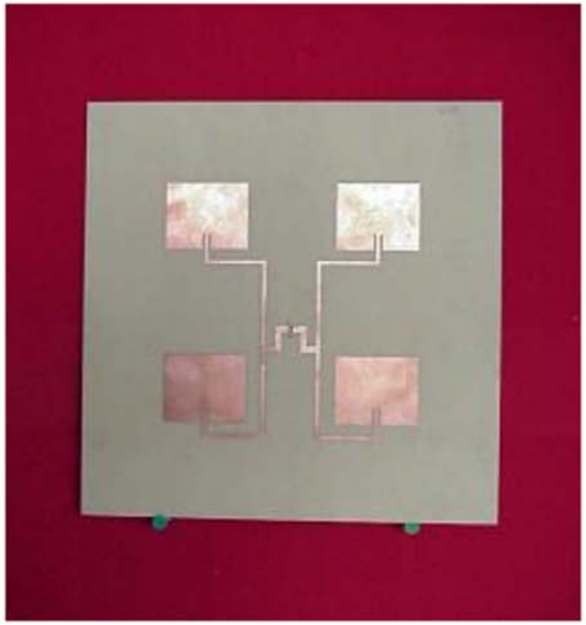

# Waveguides - planar

- With quasi-TEM wave (operation from DC possible): **microstrip**, stripline, …
- Parameters are function of frequency! (slight dispersion)

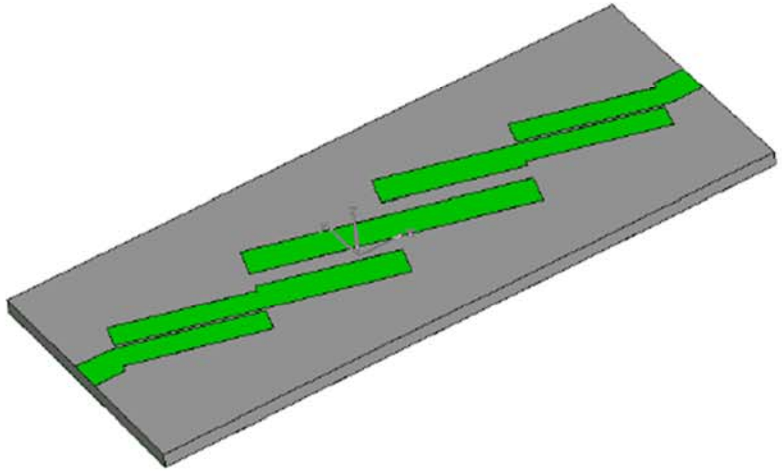


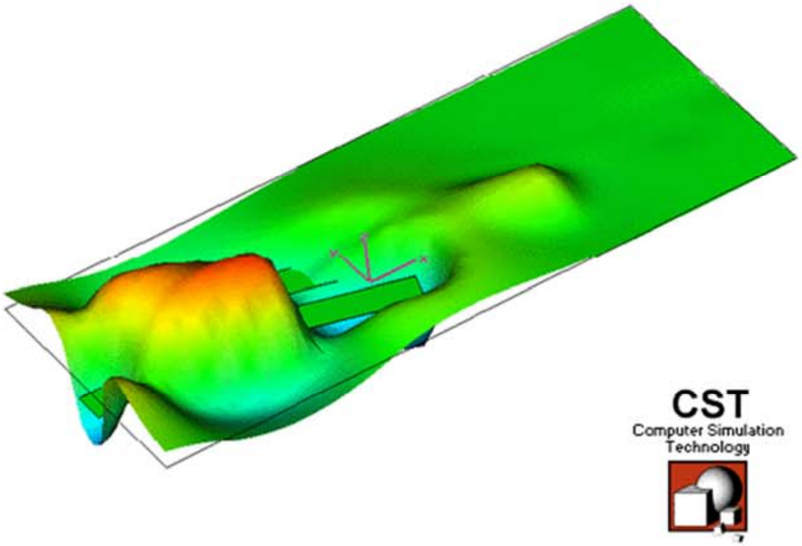


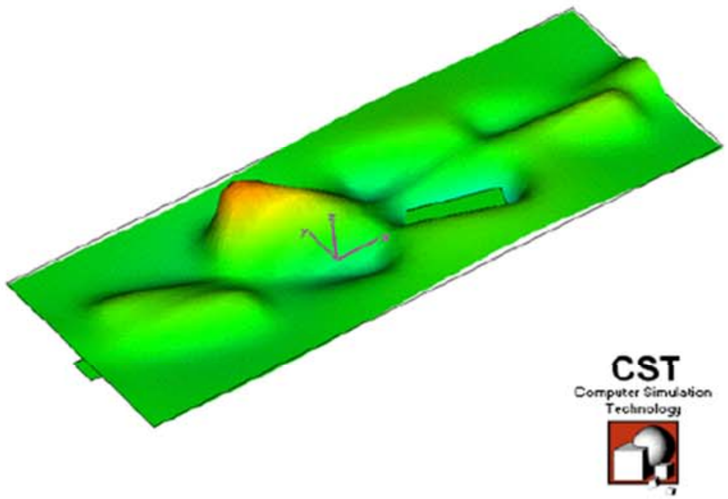


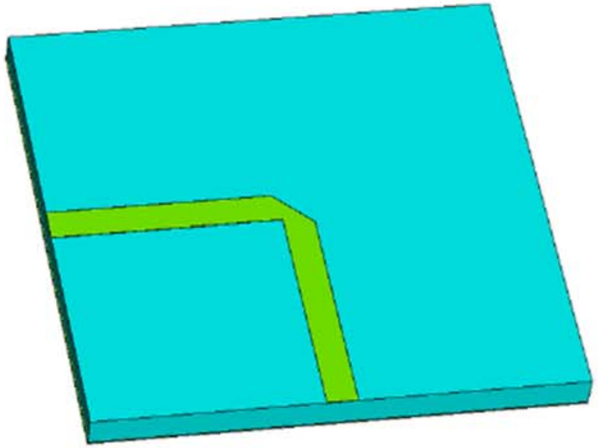
# Waveguides – planar - microstrip

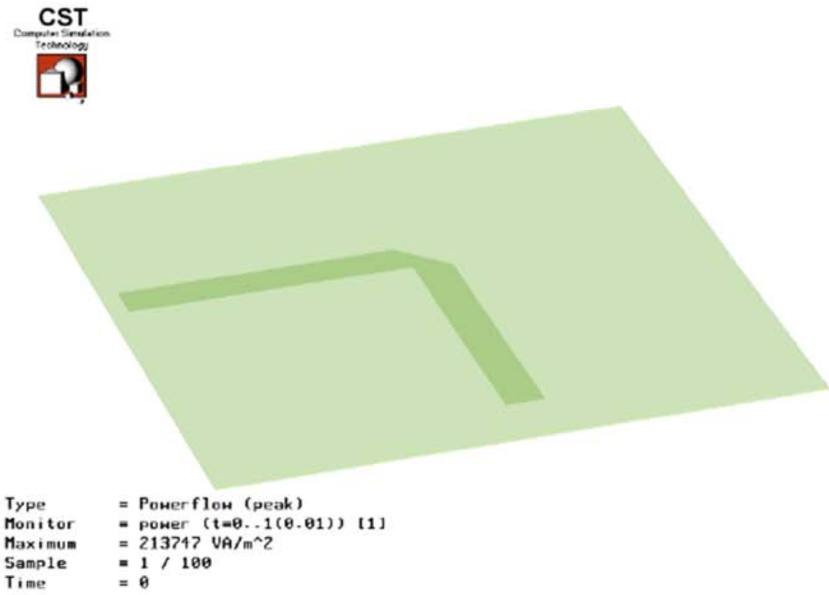


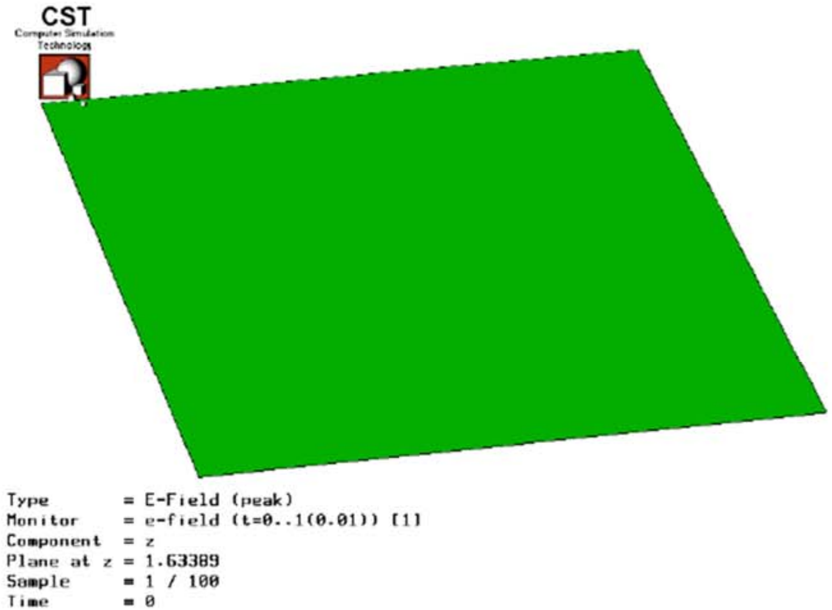


# Waveguides – planar - microstrip



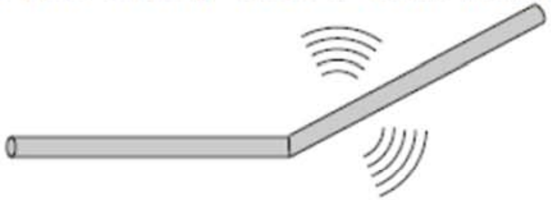


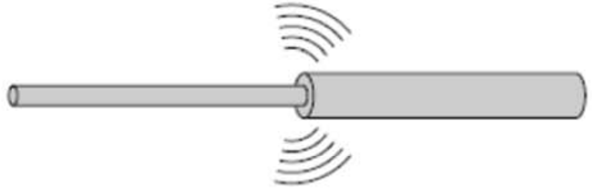



# Radiation

- Radiation is caused by *accelerating (deccelerating) charge – time varying current* (usually time-harmonic), discontinuities

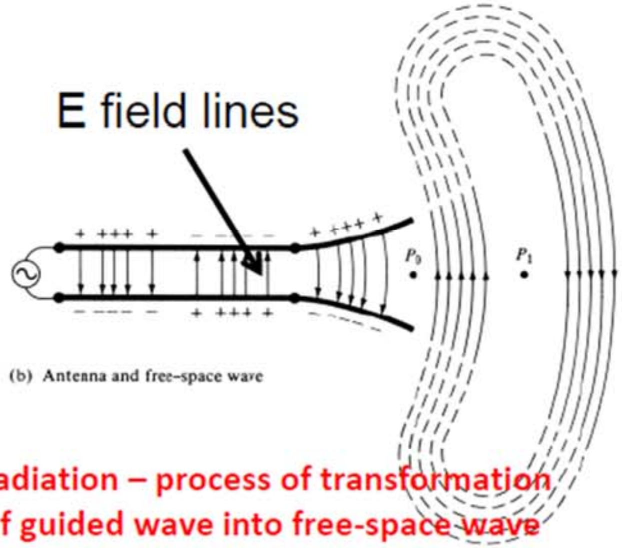
$$\nabla \cdot \boldsymbol{J} = -\frac{\partial \rho}{\partial t}$$





- A stationary charge will not radiate EM waves – zero current → no magnetic field, no radiated power

$$P_{rad} = \frac{1}{2}\Re \oint \boldsymbol{E} \times \boldsymbol{H} dS$$



(b) Antenna and free-space wave

**radiation – process of transformation of guided wave into free-space wave**

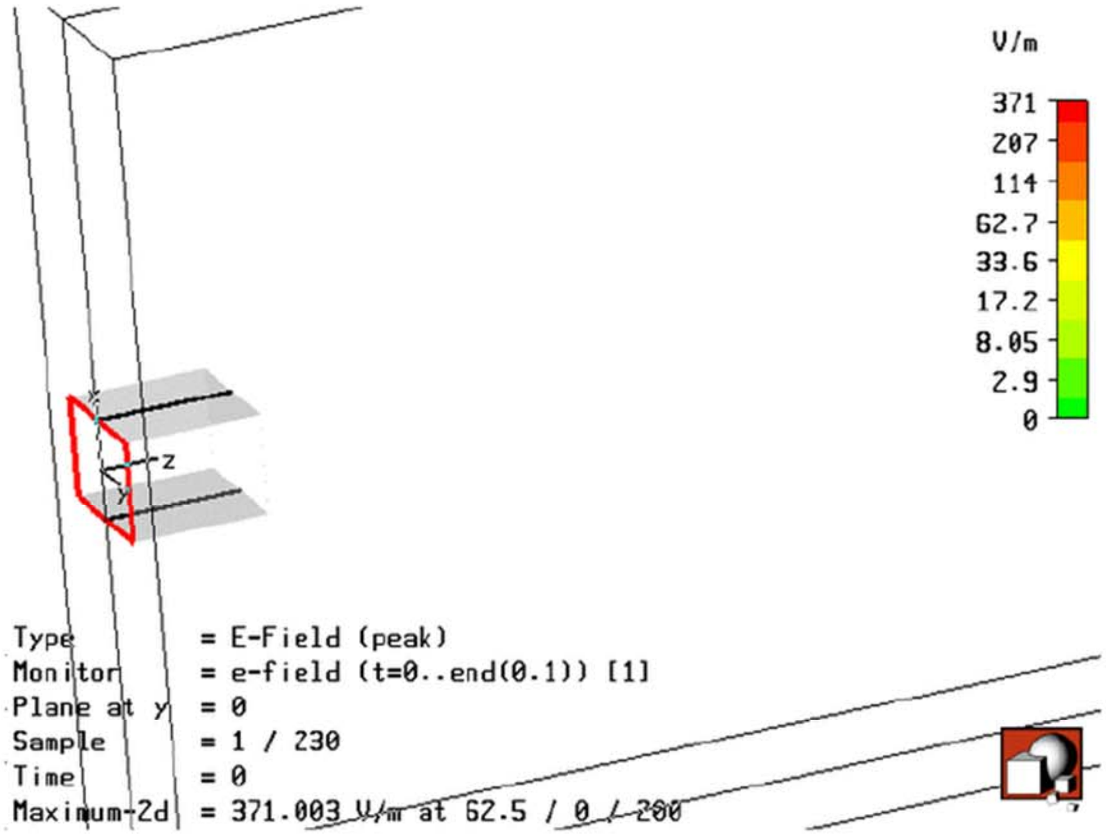
**Electric field lines:**

- Start on positive charges and end on negative charges
- Start on a positive charge and end at infinity
- Start at infinity and end on a negative charge
- Form closed loops neither starting or ending on any charge

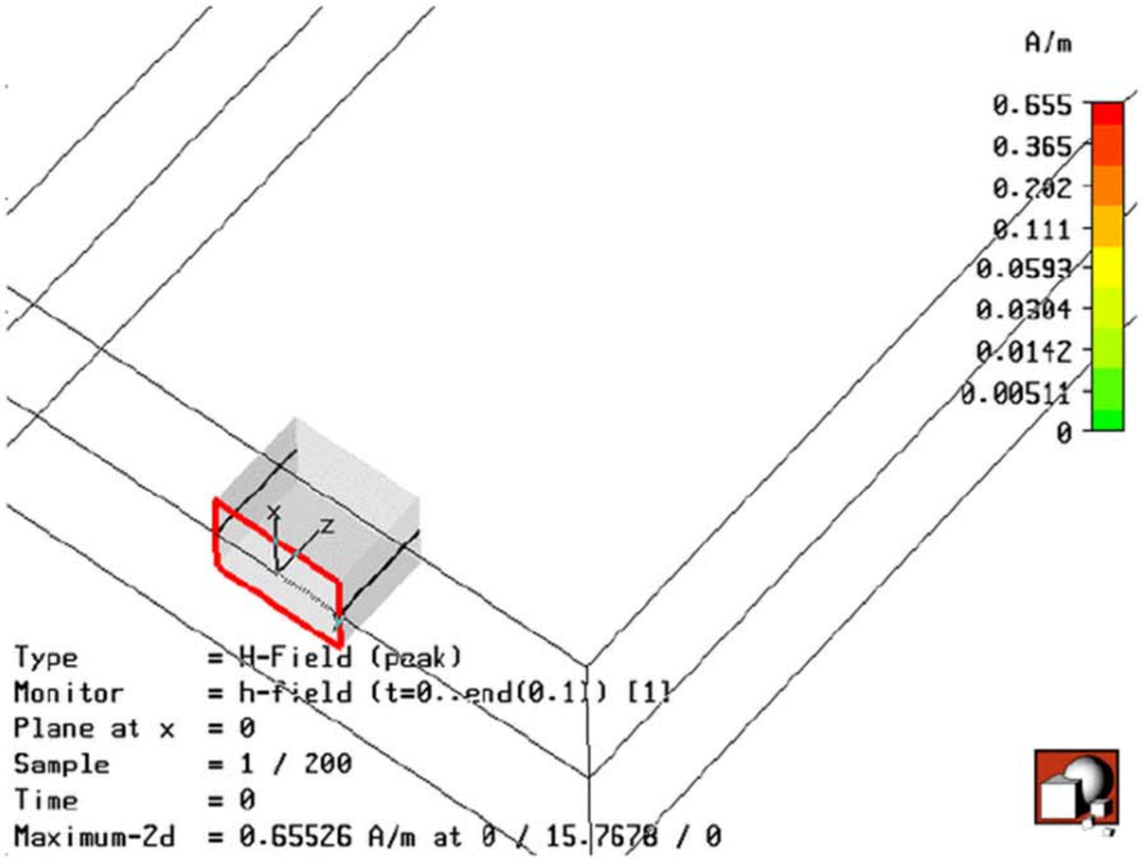
**Magnetic field lines:**

- Always form closed loops encircling current because physically there are no magnetic charges
- Mathematically it is often convenient to introduce equivalent magnetic charges and magnetic currents

# Radiation - E

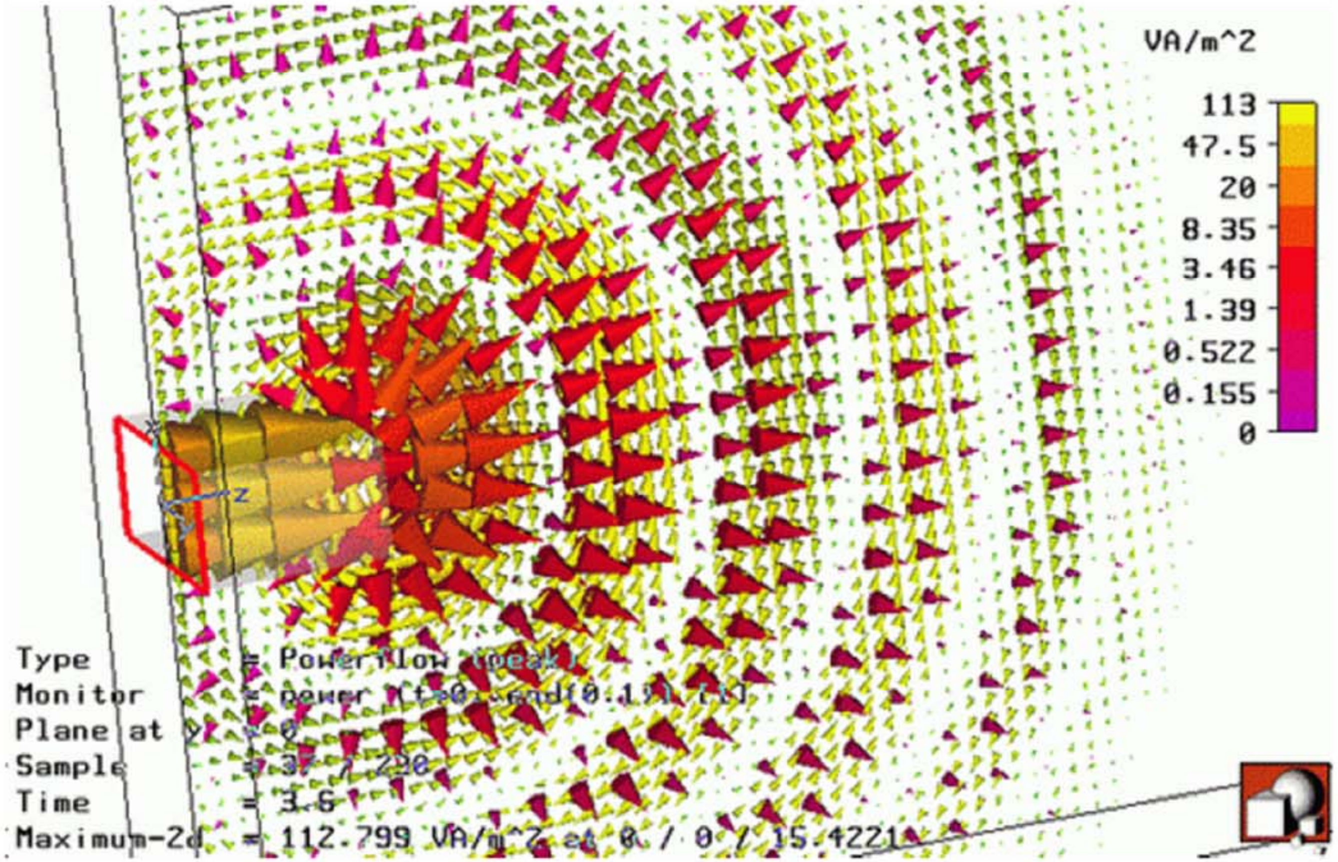

V/m
371
207
114
62.7
33.6
17.2
8.05
2.9
0
z
y
Type = E-Field (peak)
Monitor = e-field (t=0..end(0.1)) [1]
Plane at y = 0
Sample = 1 / 230
Time = 0
Maximum-2d = 371.003 V/m at 62.5 / 0 / 200

# Radiation - H

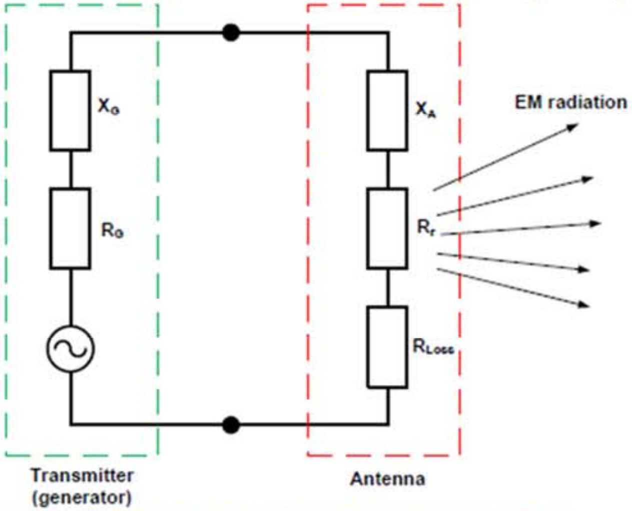

A/m
0.655
0.365
0.202
0.111
0.0593
0.0304
0.0142
0.00511
0
x
z
Type = H-Field (peak)
Monitor = h-field (t=0..end(0.1)) [1]
Plane at x = 0
Sample = 1 / 200
Time = 0
Maximum-2d = 0.65526 A/m at 0 / 15.7678 / 0

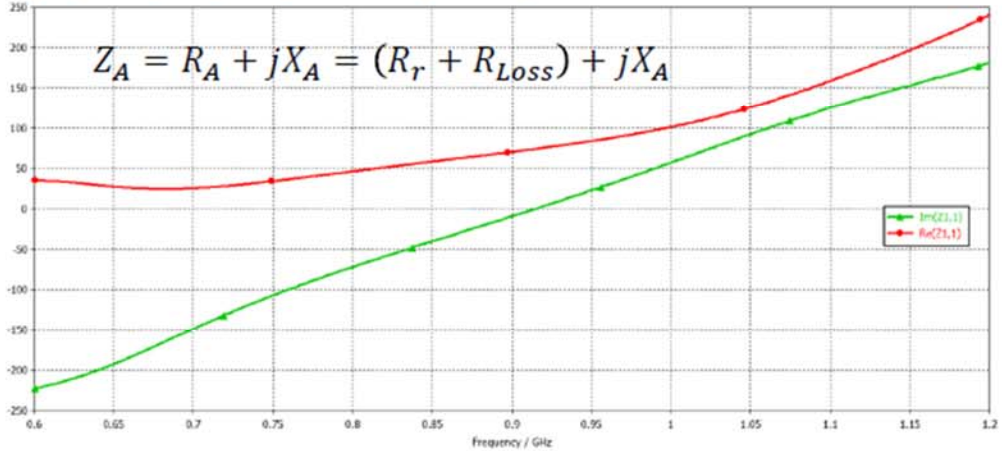
# Radiation – power flow (Poynting vector)

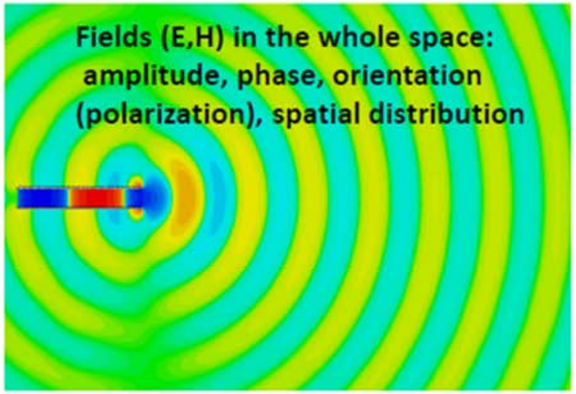
$$\boldsymbol{S} = \boldsymbol{E} \times \boldsymbol{H}$$

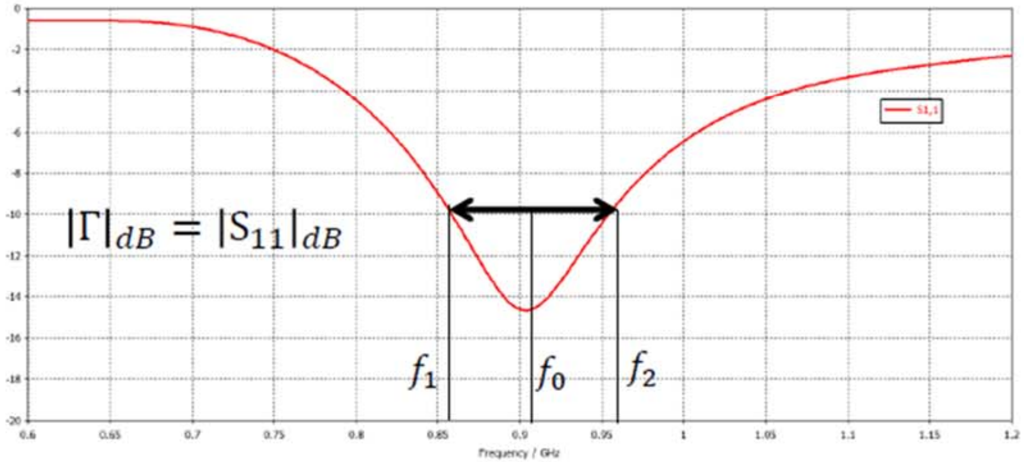


# Antenna as a circuit element




$$\Gamma = \frac{Z_A - Z_0}{Z_A + Z_0}$$

$$|\Gamma|_{dB} = 20\log(|\Gamma|)$$

$$P_{reflected} = P_{input}|\Gamma|^2$$

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

**Relative impedance bandwidth**

$$BW = \frac{f_2 - f_1}{f_0} = \frac{f_2 - f_1}{\sqrt{f_1 f_2}}$$

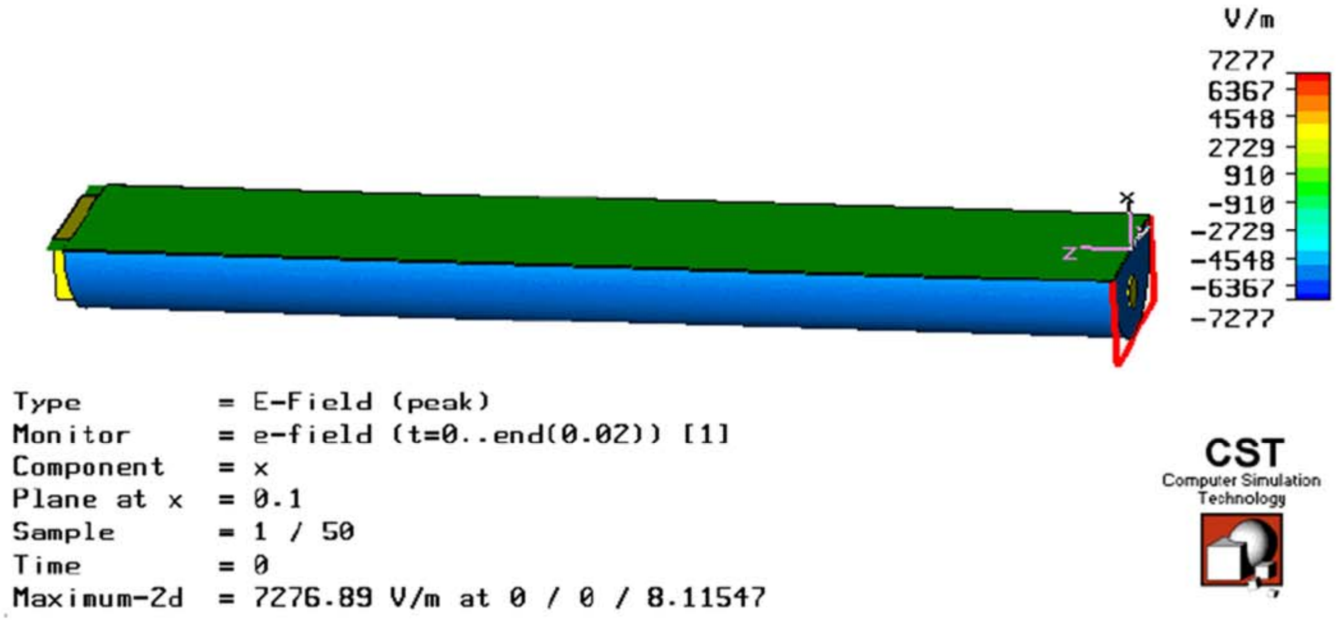
**Radiation efficiency**

$$\eta_r = \frac{R_r}{R_r + R_{Loss}}$$

# Matching

$$\Gamma = \frac{Z_A - Z_0}{Z_A + Z_0} \qquad VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$$|\Gamma|_{dB} = 20\log(|\Gamma|)$$



# Elementary electric dipole

*dz* piece of electric current $I$ is placed at origin in the z-axis, dipole length $\mathbf{L} \ll \boldsymbol{\lambda}$ $(\boldsymbol{L} \rightarrow \mathbf{0})$

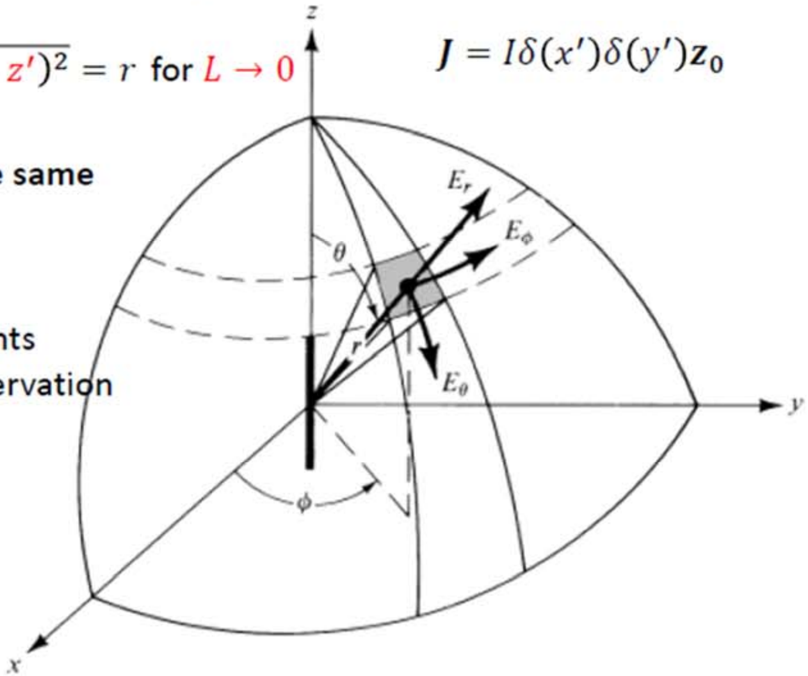
$$\boldsymbol{A}(\boldsymbol{r}) = \frac{\mu}{4\pi}\int_V \boldsymbol{J}(\boldsymbol{r}')\frac{e^{-jkR}}{R}dV' \qquad R = |\boldsymbol{r}-\boldsymbol{r}'| = \sqrt{x^2+y^2+(z-z')^2} = r \text{ for } L \rightarrow 0$$

$$\boldsymbol{J} = I\delta(x')\delta(y')\mathbf{z}_0$$

$$A_z(\boldsymbol{r}) = \frac{\mu I}{4\pi}\frac{e^{-jkr}}{r}\int_{-L/2}^{L/2} dz' = \frac{\mu I L}{4\pi}\frac{e^{-jkr}}{r}$$

**Vector potential has the same orientation as current!**

$$A_x = A_y = 0$$




Transformation between rectangular and spherical vector components (it is convenient here to describe source points in cartesian and observation points in spherical coordinates respectively)

$$\begin{bmatrix} A_r \\ A_\theta \\ A_\phi \end{bmatrix} = \begin{bmatrix} \sin\theta\cos\phi & \sin\theta\sin\phi & \cos\theta \\ \cos\theta\cos\phi & \cos\theta\sin\phi & -\sin\theta \\ -\sin\phi & \cos\phi & 0 \end{bmatrix}\begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix}$$

Spherical components of vector potentials in spherical coordinates:

$$A_r(\theta,\phi,r) = A_z\cos\theta = \frac{\mu I L}{4\pi}\frac{e^{-jkr}}{r}\cos\theta$$

$$A_\theta(\theta,\phi,r) = -A_z\sin\theta = -\frac{\mu I L}{4\pi}\frac{e^{-jkr}}{r}\sin\theta$$

$$A_\phi(\theta,\phi,r) = 0$$

$$\boldsymbol{E} = -j\omega\boldsymbol{A} - \frac{j}{\omega\mu\epsilon}\nabla(\nabla\cdot\boldsymbol{A})$$

$$\mathbf{H} = \frac{1}{\mu}\nabla\times\boldsymbol{A}$$

# Elementary electric dipole

Components of electric and magnetic fields generated by an elementary electric dipole

$$H_\phi(r,\theta) = \frac{jkIL}{4\pi}\sin\theta\left[\frac{1}{r}+\frac{1}{jkr^2}\right]e^{-jkr}$$

$$E_r(r,\theta) = \frac{Z_0IL}{2\pi}\cos\theta\left[\frac{1}{r^2}+\frac{1}{jkr^3}\right]e^{-jkr}$$

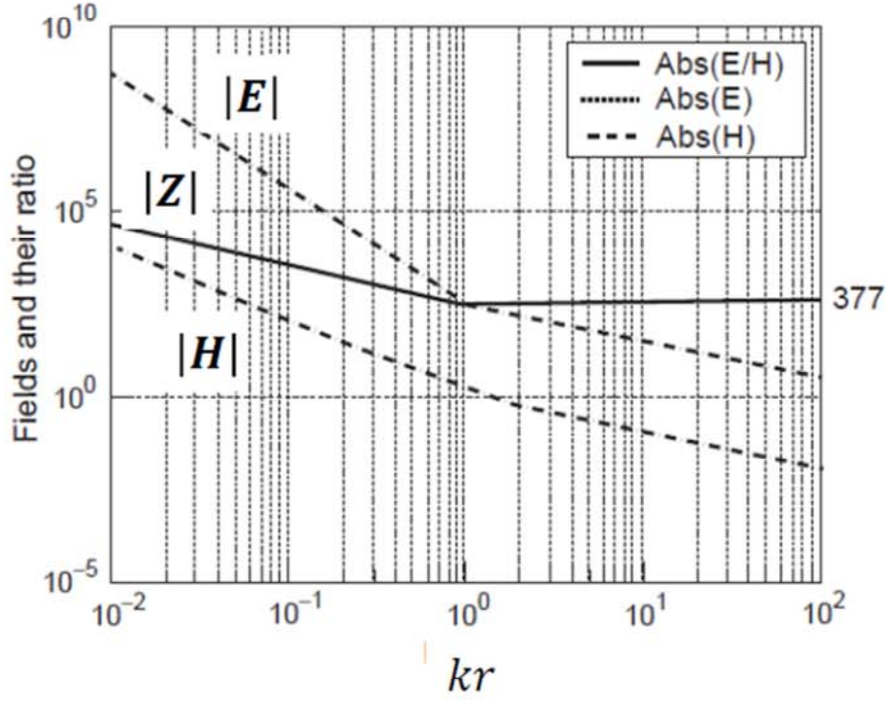
$$E_\theta(r,\theta) = \frac{jkZ_0IL}{4\pi}\sin\theta\left[\frac{1}{r}+\frac{1}{jkr^2}-\frac{1}{k^2r^3}\right]e^{-jkr}$$

$H_r = H_\theta = 0$

$E_\phi = 0$ Fields are not function of $\phi$

General distance out of sources

These expressions are valid everywhere except on the source itself. In most cases we are interested only in the far-field, i.e. retain only $1/r$ terms. Generally, the radiated fields are vector functions of spherical coordinates $r, \theta, \phi$.

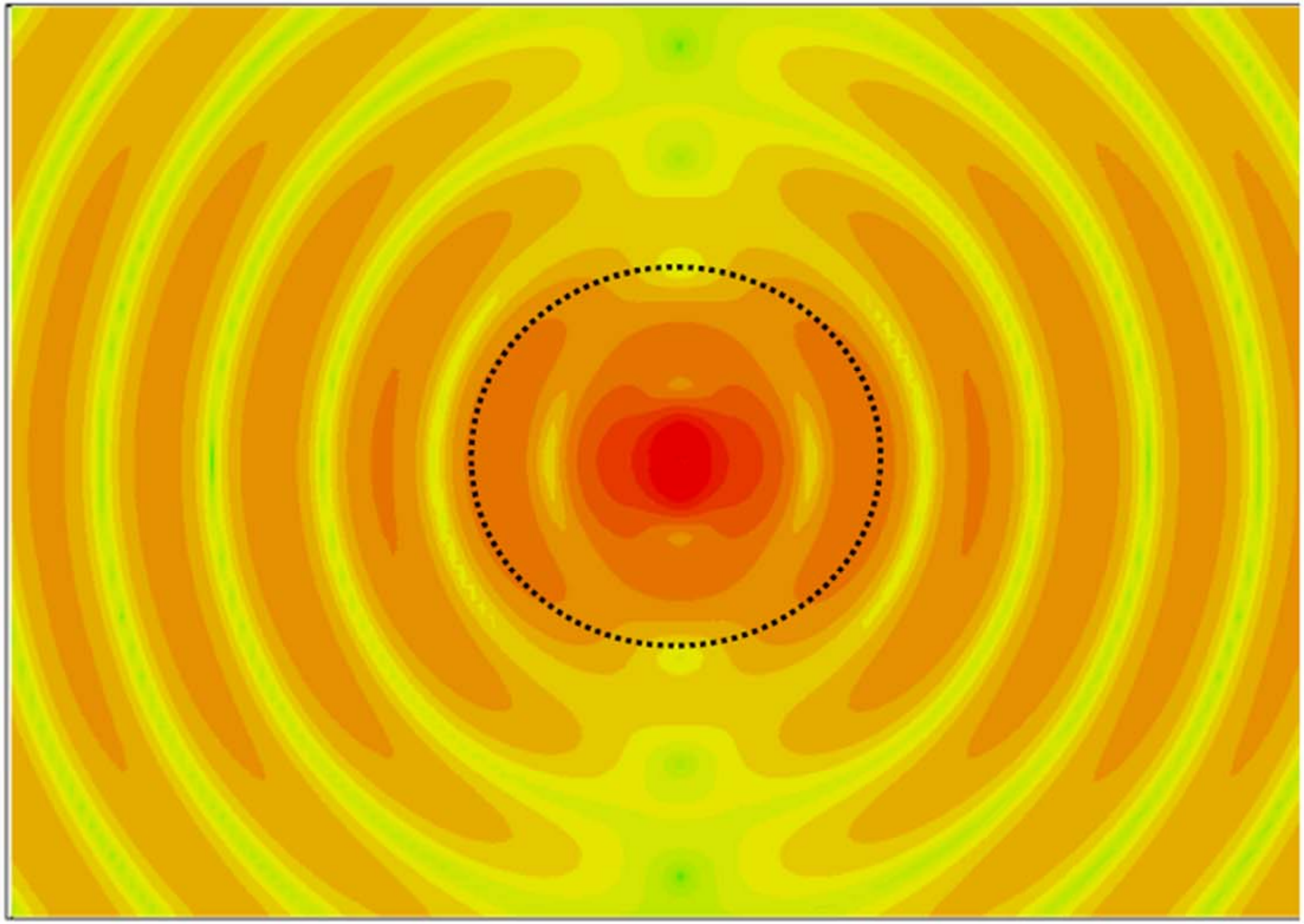



(distance)

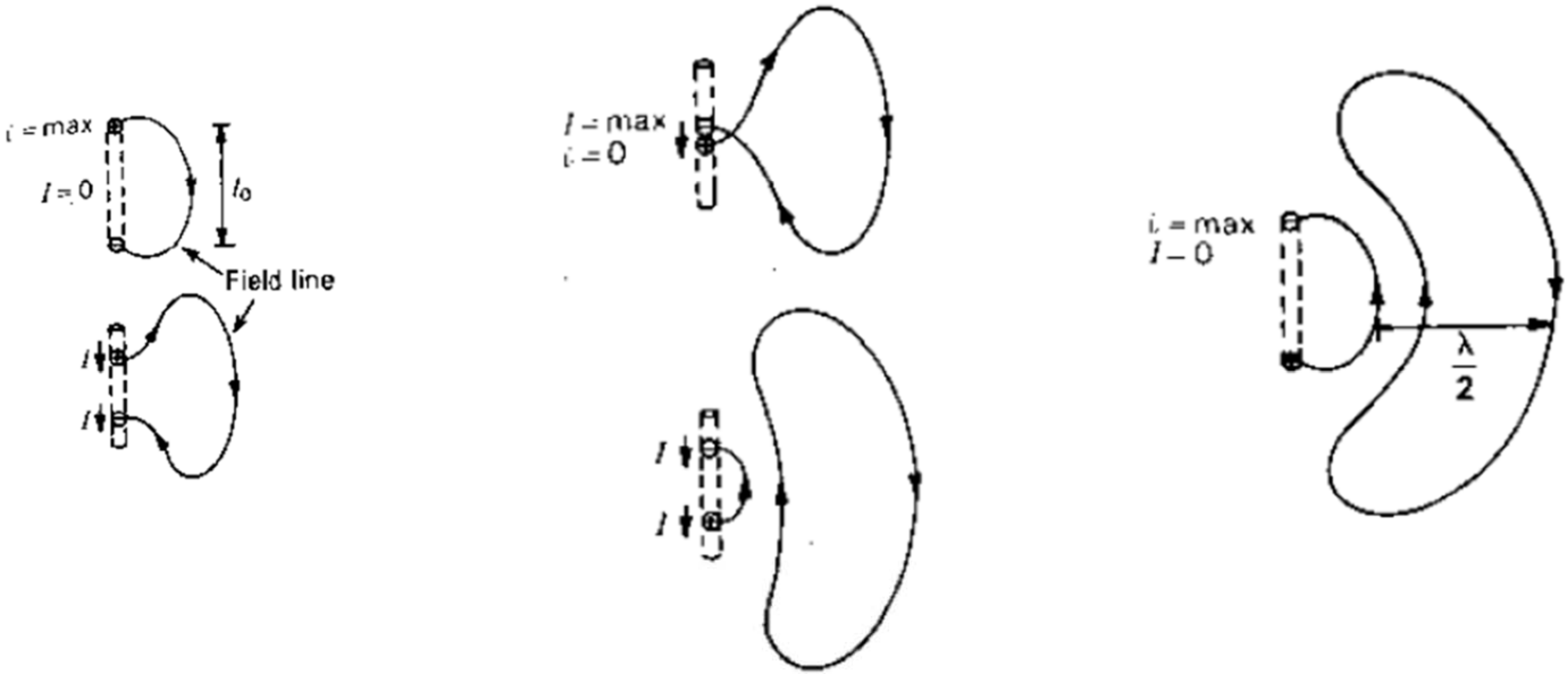
- E field is always greater than H field (its electric dipole)
- $kr = 1$ ($r = \lambda/2\pi$) is an important point (radian distance, radian sphere)
- $|Z| = \left|\frac{E}{H}\right| = 120\pi \cong 377\Omega$ if $kr > 1$

# Elementary electric dipole

Short electric dipole ($L = \lambda/10$), magnitude of E-field intensity, radian-sphere $kr = 1$ ($r = \lambda/2\pi$) shown



# Elementary electric dipole




Oscillating electric dipole consisting of two electric charges in simple harmonic motion, showing propagation of an electric field line and its detachment (radiation) from the dipole