Instytut WAT
radioelektroniki

Antenna basic theory

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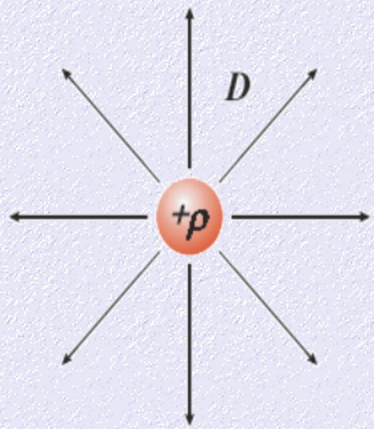
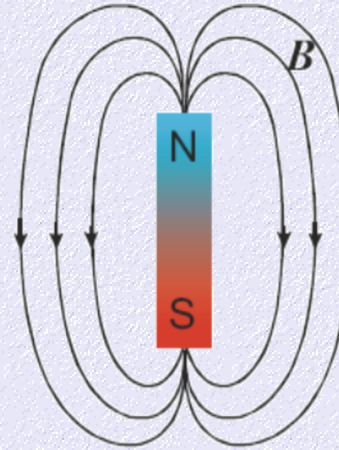
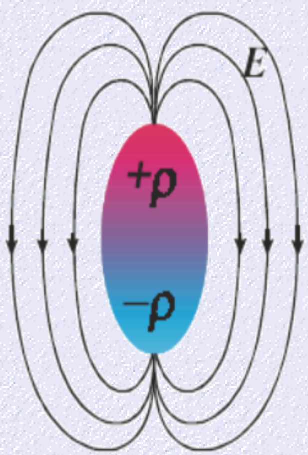
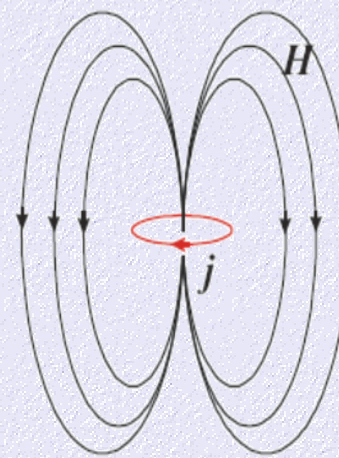
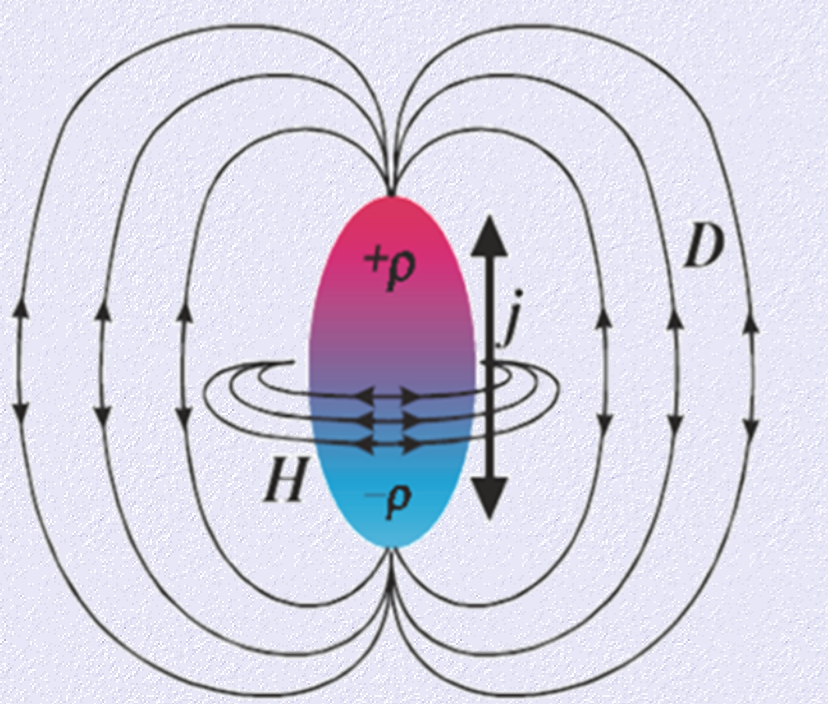
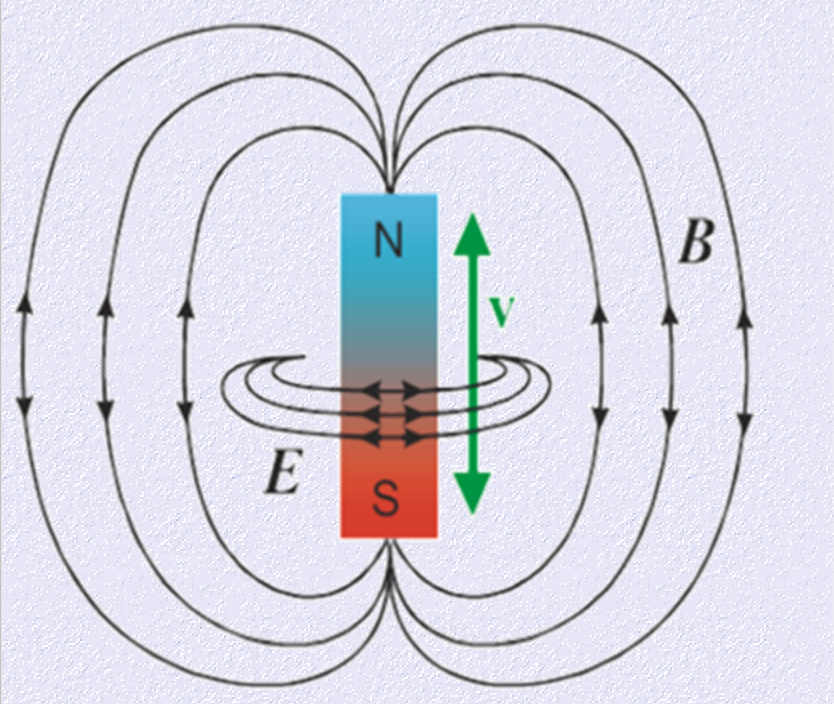
Immovable charges and magnets generate static fields ***E*** and ***H*** respectively

$\nabla \boldsymbol{D} = \rho$		$\nabla \boldsymbol{B} = 0$	
$\nabla \times \boldsymbol{E} = 0$		$\nabla \times \boldsymbol{H} = \boldsymbol{j}$	

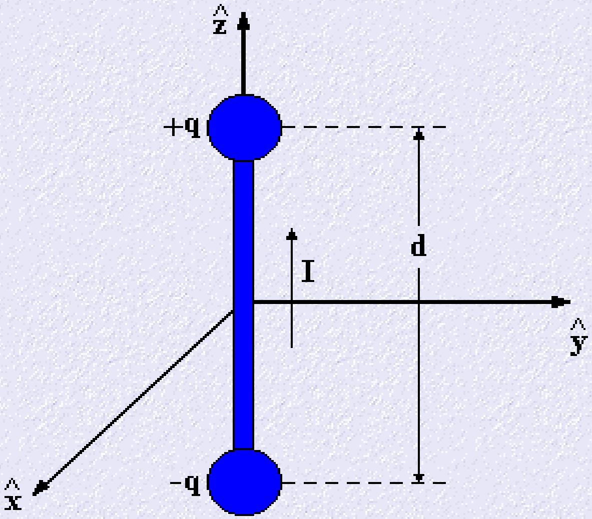
Charges or magnets movement generate dynamic and coupled ***E*** and ***H*** fields.

$\nabla D = \rho$ Gauss low	$\nabla B = 0$ no magnetic charge
$\nabla \times H = j + \frac{\partial D}{\partial t}$ Ampere low	$\nabla \times E = -\frac{\partial B}{\partial t}$ Faraday low





The simplest dynamic field fource is Hertz dipole



Dipole momentum

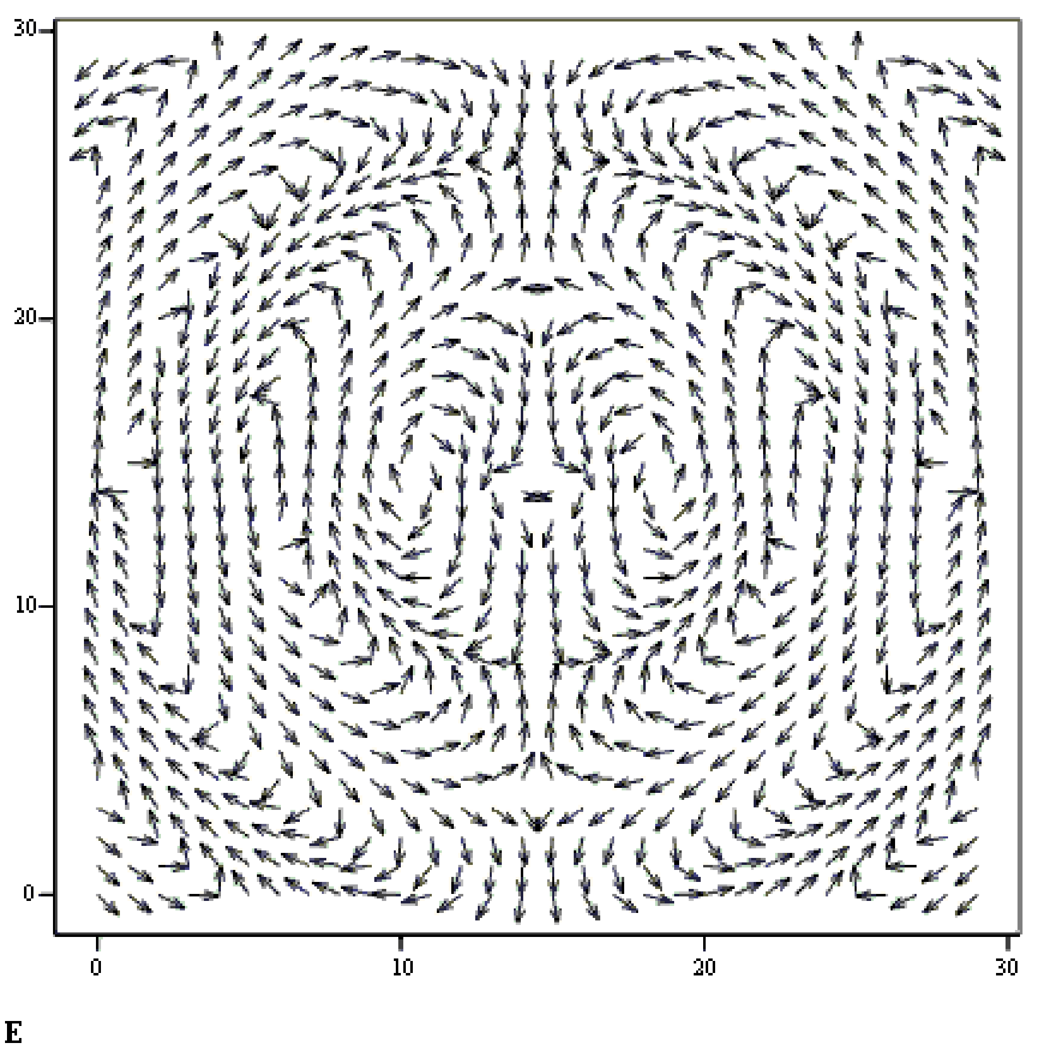
$$\boldsymbol{p} = \mathbf{z} \cdot q \cdot d$$

As d decreases q is converging to the infinity but dipole momentum remains constant

The solution of Maxwell equations for ***E*** field around Hertz dipole in Cartesian coordinates:

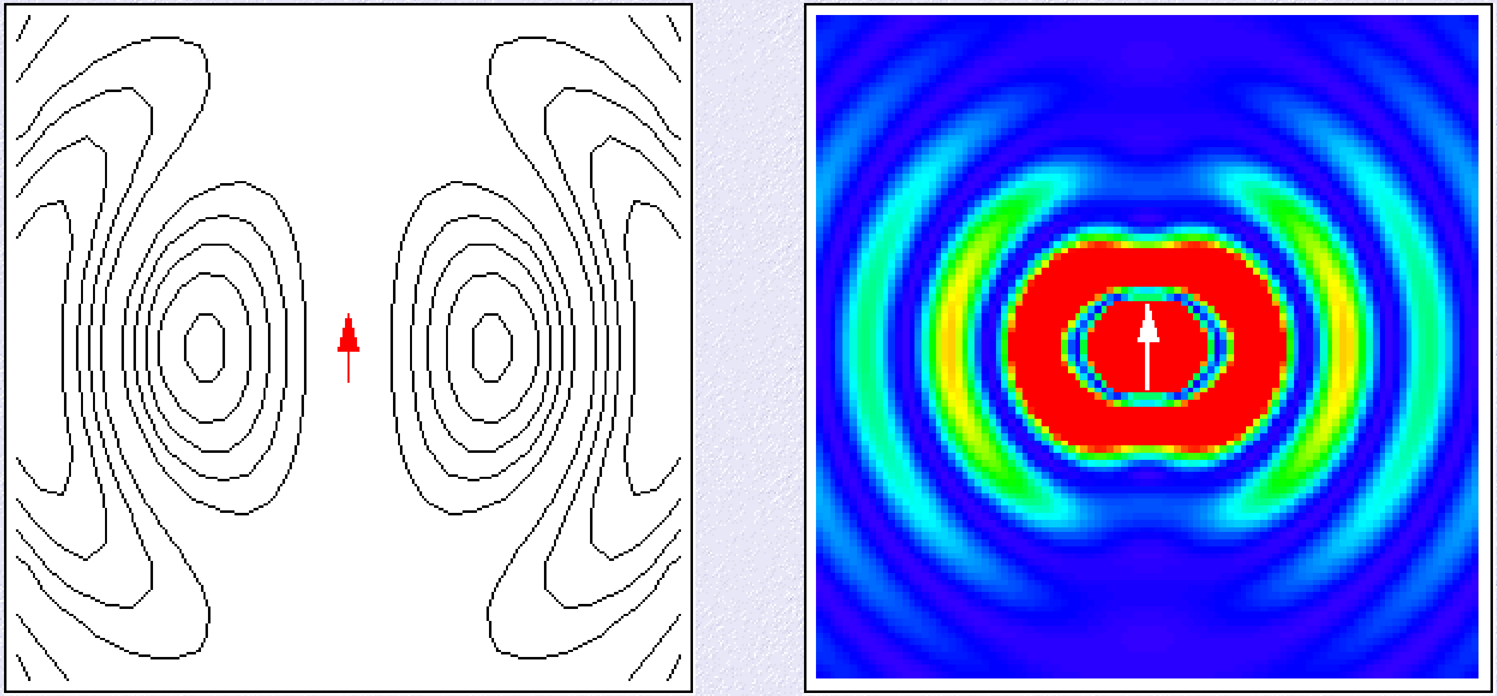
$$\underline{\mathbf{E}} = \begin{bmatrix} \frac{1}{4}\cdot x\cdot z\cdot \eta_0\cdot I\cdot d\cdot \exp\left(-j\cdot k\cdot\sqrt{x^2+y^2+z^2}\right)\cdot\dfrac{3\cdot k\cdot\sqrt{x^2+y^2+z^2} - 3\cdot j + j\cdot k^2\cdot x^2 + j\cdot k^2\cdot y^2 + j\cdot k^2\cdot z^2}{\left(x^2+y^2+z^2\right)^{\frac{5}{2}}\cdot(k\cdot\pi)} \\ \frac{1}{4}\cdot y\cdot z\cdot \eta_0\cdot I\cdot d\cdot \exp\left(-j\cdot k\cdot\sqrt{x^2+y^2+z^2}\right)\cdot\dfrac{3\cdot k\cdot\sqrt{x^2+y^2+z^2} - 3\cdot j + j\cdot k^2\cdot x^2 + j\cdot k^2\cdot y^2 + j\cdot k^2\cdot z^2}{\left(x^2+y^2+z^2\right)^{\frac{5}{2}}\cdot(k\cdot\pi)} \\ \frac{-1}{4}\cdot \eta_0\cdot I\cdot d\cdot \exp\left(-j\cdot k\cdot\sqrt{x^2+y^2+z^2}\right)\cdot\dfrac{-2\cdot z^2\cdot k\cdot\sqrt{x^2+y^2+z^2} + 2\cdot j\cdot z^2 + j\cdot k^2\cdot x^4 + 2\cdot j\cdot k^2\cdot x^2\cdot y^2 + j\cdot k^2\cdot x^2\cdot z^2 + j\cdot k^2\cdot y^4 + j\cdot k^2\cdot y^2\cdot z^2 + k\cdot\sqrt{x^2+y^2+z^2}\cdot x^2 + k\cdot\sqrt{x^2+y^2+z^2}\cdot y^2 - j\cdot x^2 - j\cdot y^2}{\left(x^2+y^2+z^2\right)^{\frac{5}{2}}\cdot(k\cdot\pi)} \end{bmatrix}$$

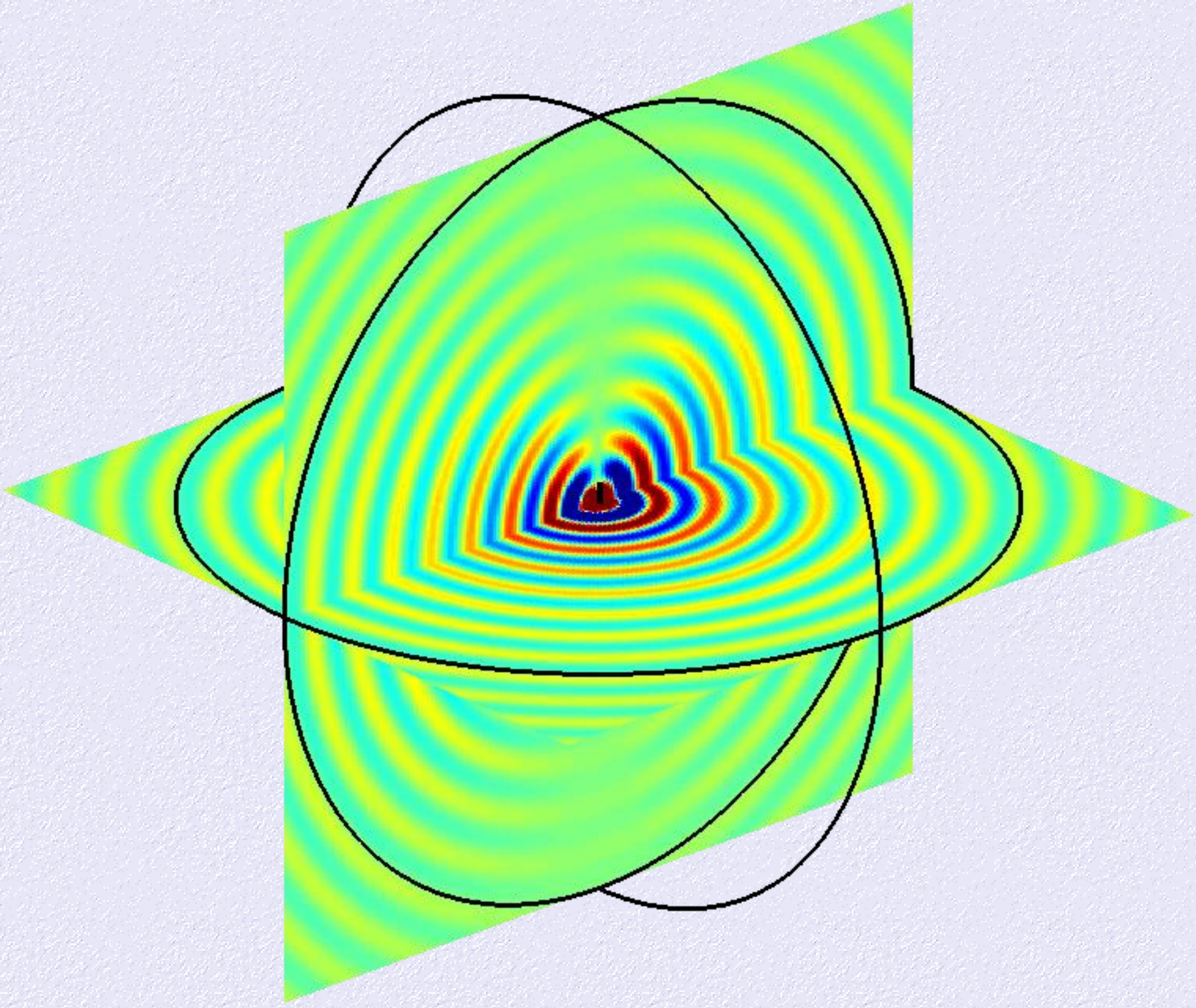
Imaging of the solution



Elementary source is ominidirectional but not isotropic

Hertz dipole – energy distribution



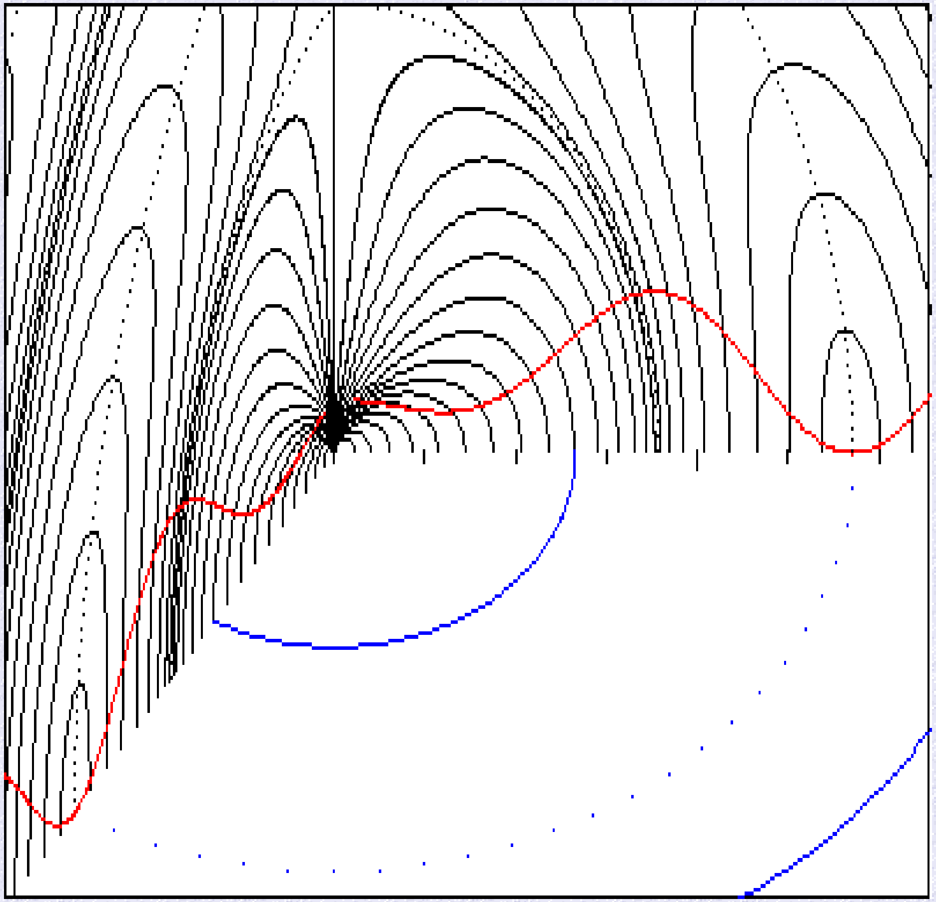


Cross-section of lines of force around Hertz dipole

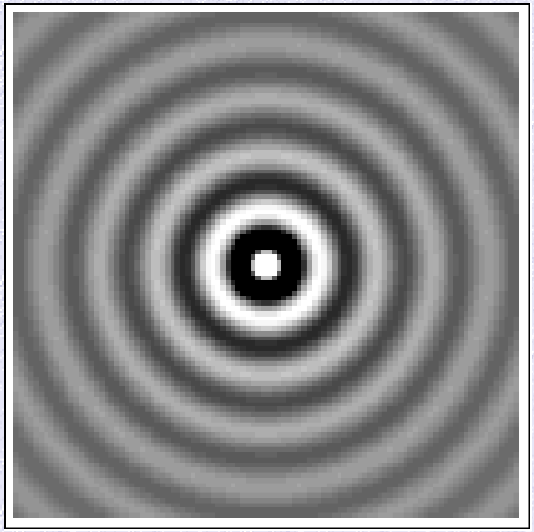
magnetic field

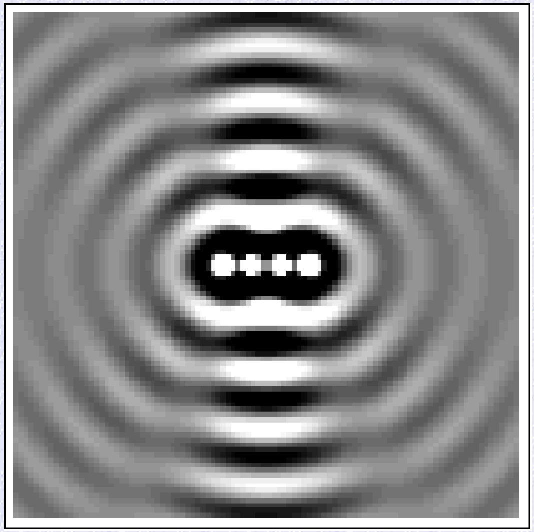
electric field

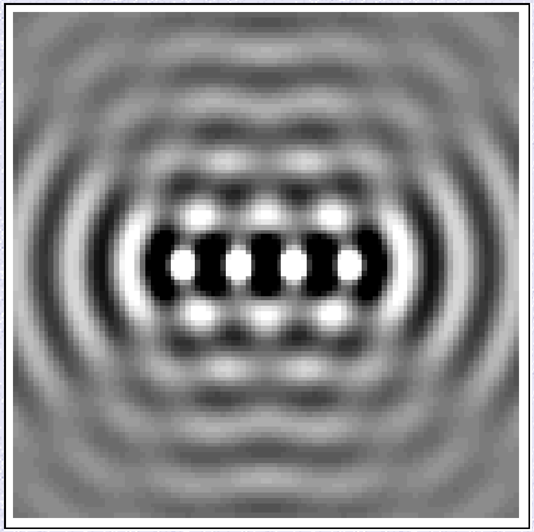
$|\boldsymbol{E}| \,/\, |\boldsymbol{H}| = 120\pi$



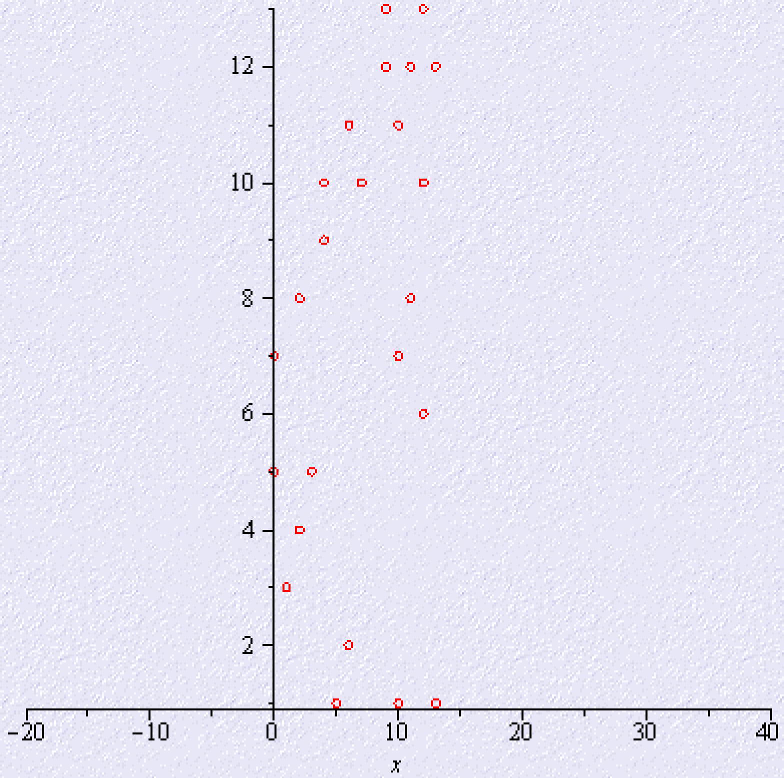
Each antenna is a set of many Hertz dipoles
External fields is the results of interference of the set

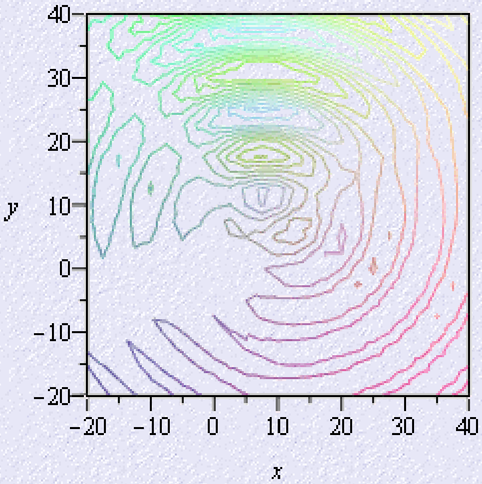




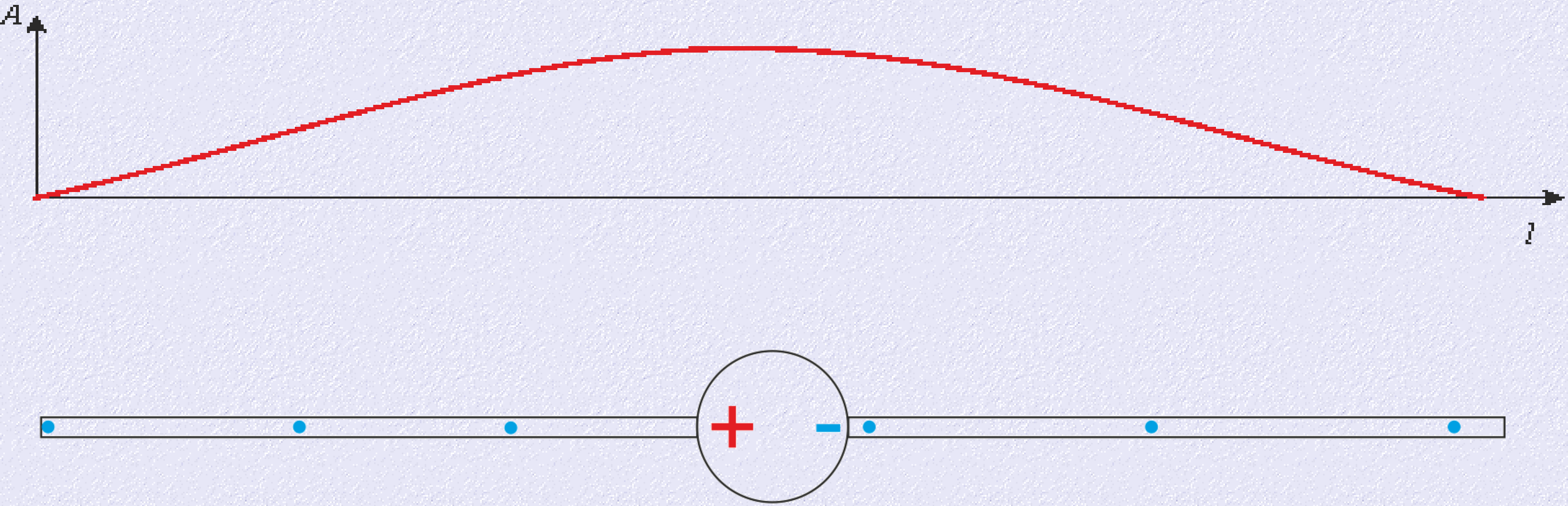


Even random set of dipoles has som radiation properties



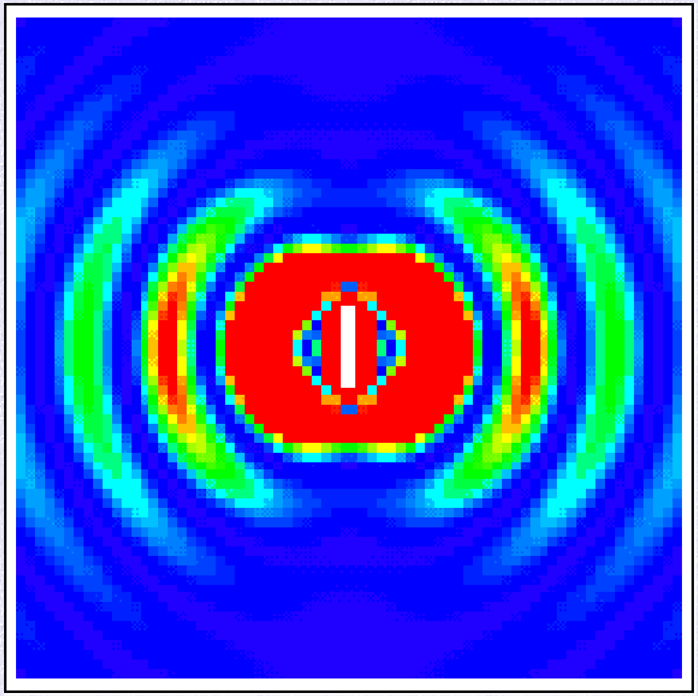


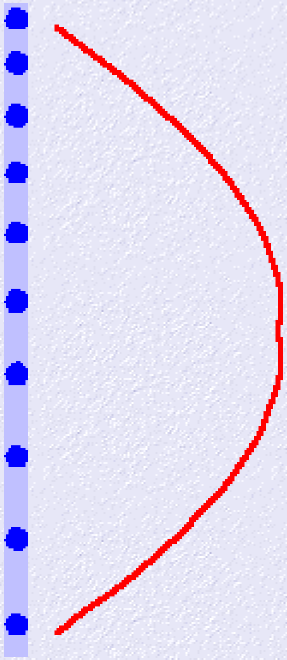
The simplest technically achievable set is short wire with electric current
One of the most popular is half-wave dipole



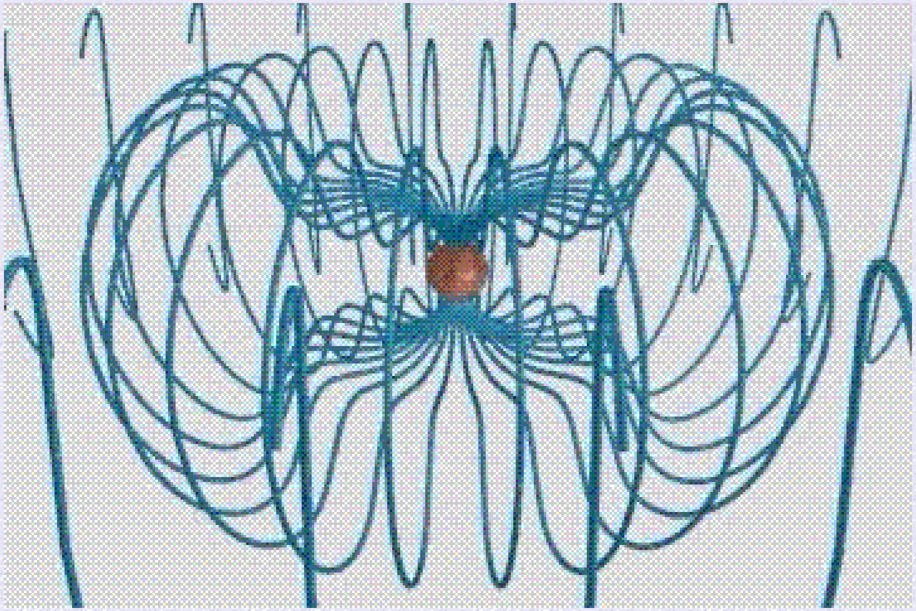
The electric current can flow in the open circuit!

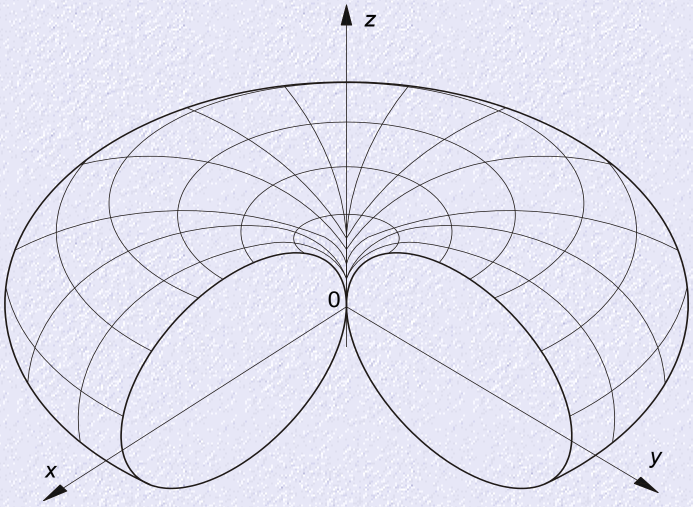
Electric field energy distribution around half-wave dipole

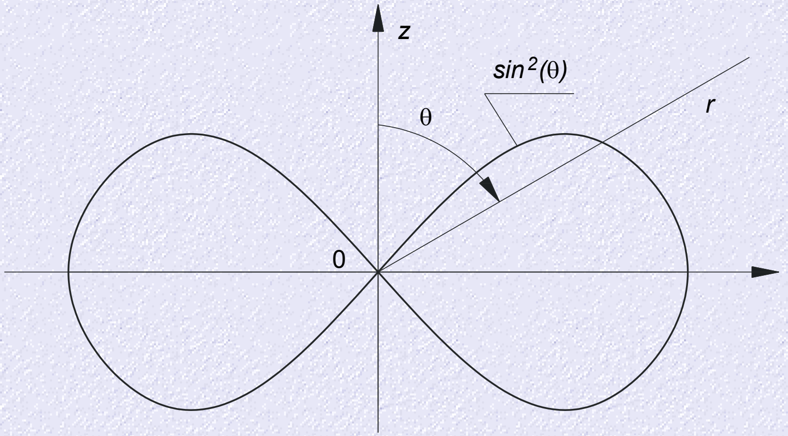




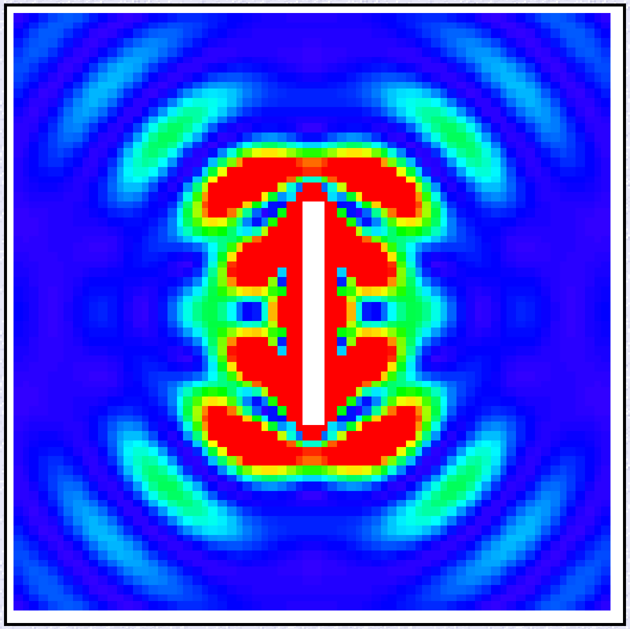
Half-wafe dipole is also omnidirectional

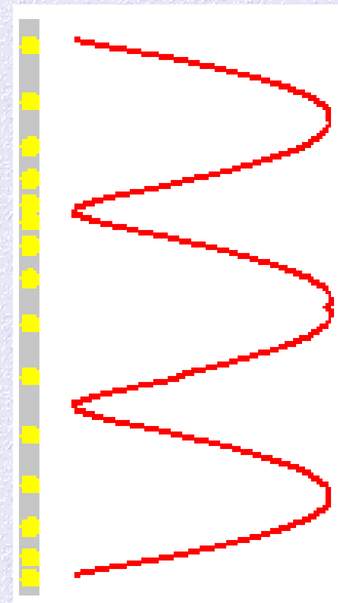




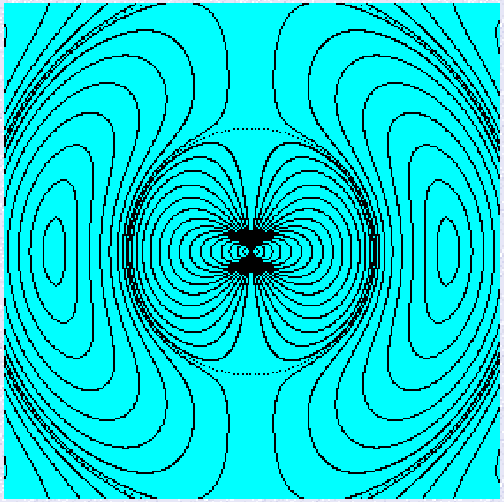


Electric field energy distribution around one and a half-wave dipole

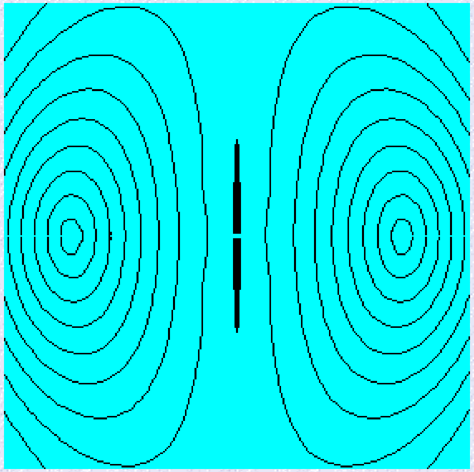




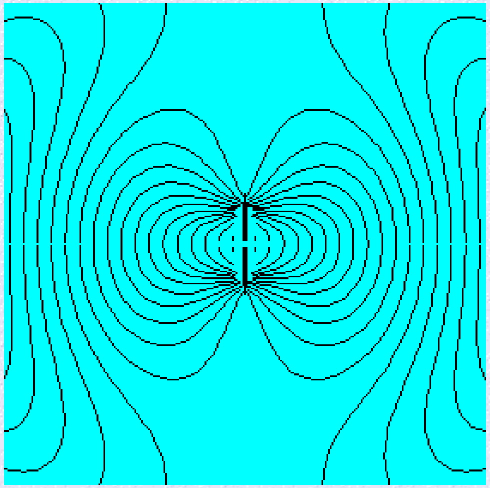
Hertz dipole



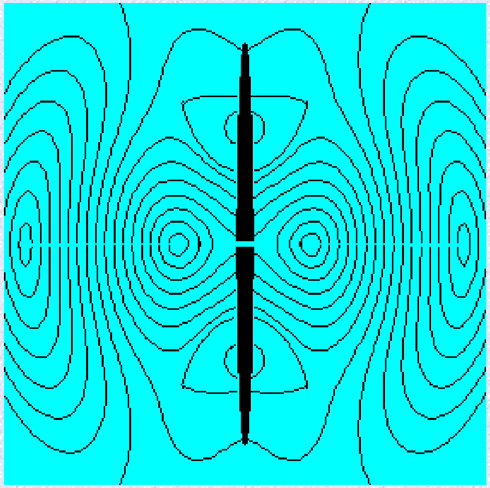
$\lambda/2$



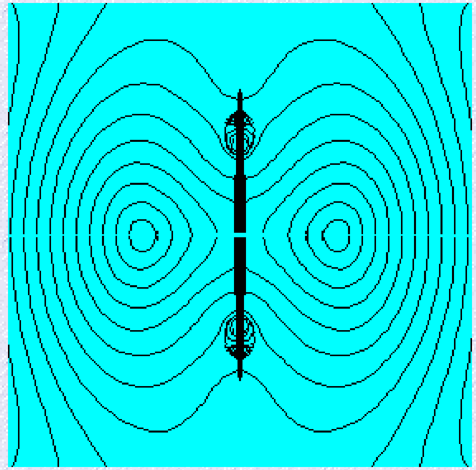
$\lambda/4$



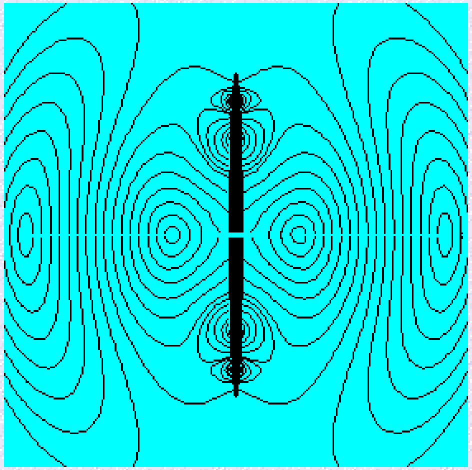
$3\lambda/2$



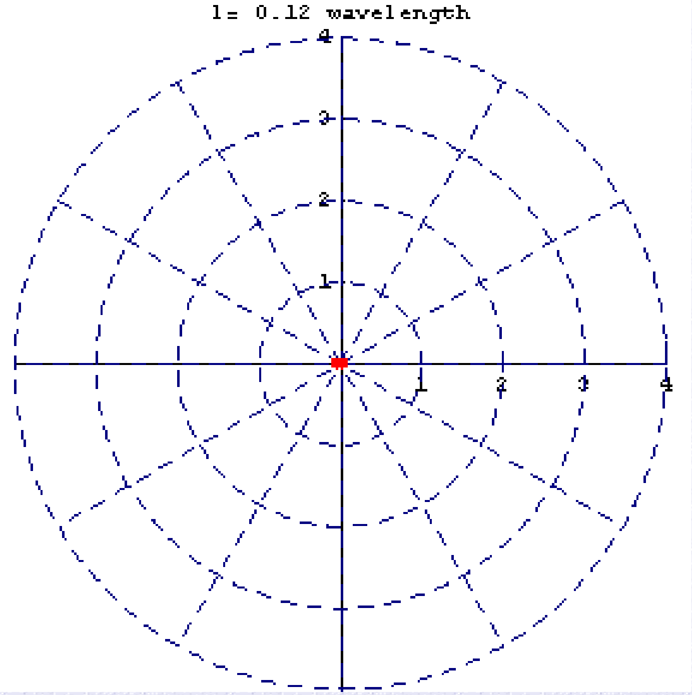
$3\lambda/4$

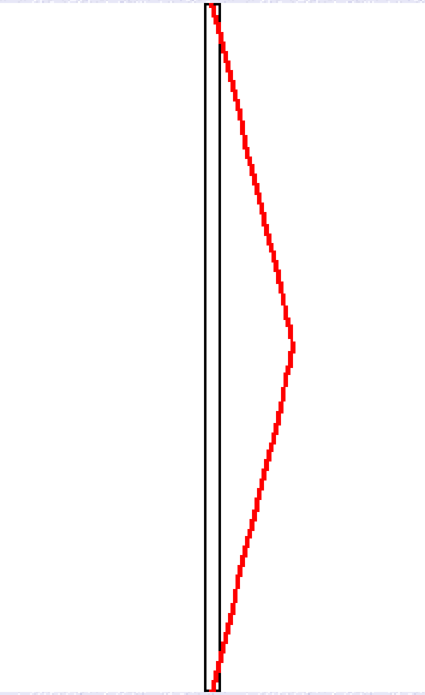


$5\lambda/4$



Antenna directivity is depend on current distribution along wire





Basic parameters of antennas

Input resistance

$$R_{\mathrm{in}} = R_{\mathrm{R}} + r$$

radiation resistance

loss resistance

(responsible for noise generation)

radiating power

$$R_{\mathrm{R}} = \frac{P_R}{I^2}$$

maximum value of electric current in the powering (feeding) point

Radiation resistance is very important parameter that allow to determine noise properties of antenna

Antenna noise temperature

Every object with a physical temperature above zero and possessing some finite conductivity radiates EM power.

This power depends on the ability of the object's surface to let the heat leak out.

This radiated heat power is associated with the so-called equivalent temperature or brightness temperature of the body via the power-temperature relation

$$P_B = kT_B\Delta f \quad [\mathrm{W}]$$

k is Boltzmann's constant ($1.38\cdot10^{-23}$ [J/K])

The power radiated by the body P_B, when intercepted by the antenna, creates power at the antenna terminals P_A.
The equivalent temperature associated with the received power P_A at the antenna terminals is called antenna temperature T_A of the object:

$$P_A = kT_A \Delta f \quad [\mathrm{W}]$$

The received power can be calculated if the antenna effective aperture (receiving area) A_e [m^2] is known and if the power density W_B [W/m^2] created by the bright body at the antenna's location is known

$$P_A = A_e W_B$$

If the body radiates isotropically (in all directions)

$$W_B = \frac{P_B}{4\pi R^2}$$

For isotropic radiation and losless and noiseless antenna ($r = 0$) the noise power at antenna terminals is proportional to body temperature

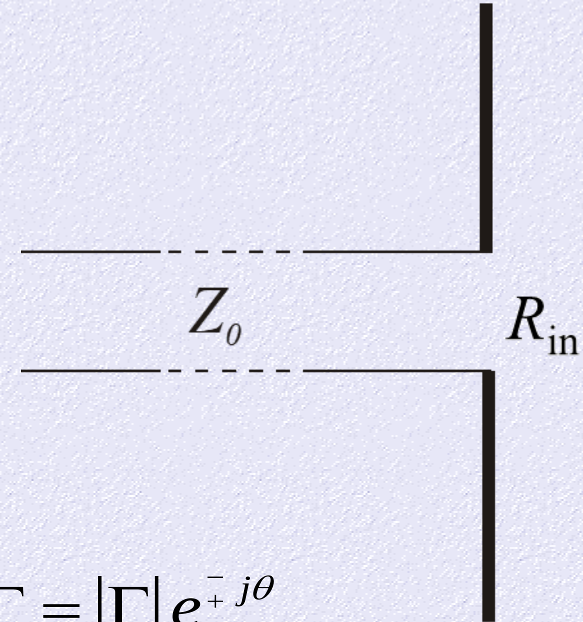
$$P_A = kT_B \Delta f \quad \text{[W]}$$

This is the same power as the power that would be generated by a resistor at temperature T_B

Antenna efficiency

$$\eta = \frac{P_{\mathrm{R}}}{P_{\mathrm{tot}}} = \frac{P_{\mathrm{R}}}{P_R + P_{\mathrm{loss}}} < 1$$

Antenna matching



Reflection coefficient $\Gamma = \frac{u_{refl}}{u_{in}} = \frac{R_{in} - Z_0}{R_{in} + Z_0}$

$$\Gamma = |\Gamma| e^{\mp j\theta}$$

$$\Gamma = |\Gamma| e^{\pm j\theta} \qquad |\Gamma| \in < 0,1 >$$

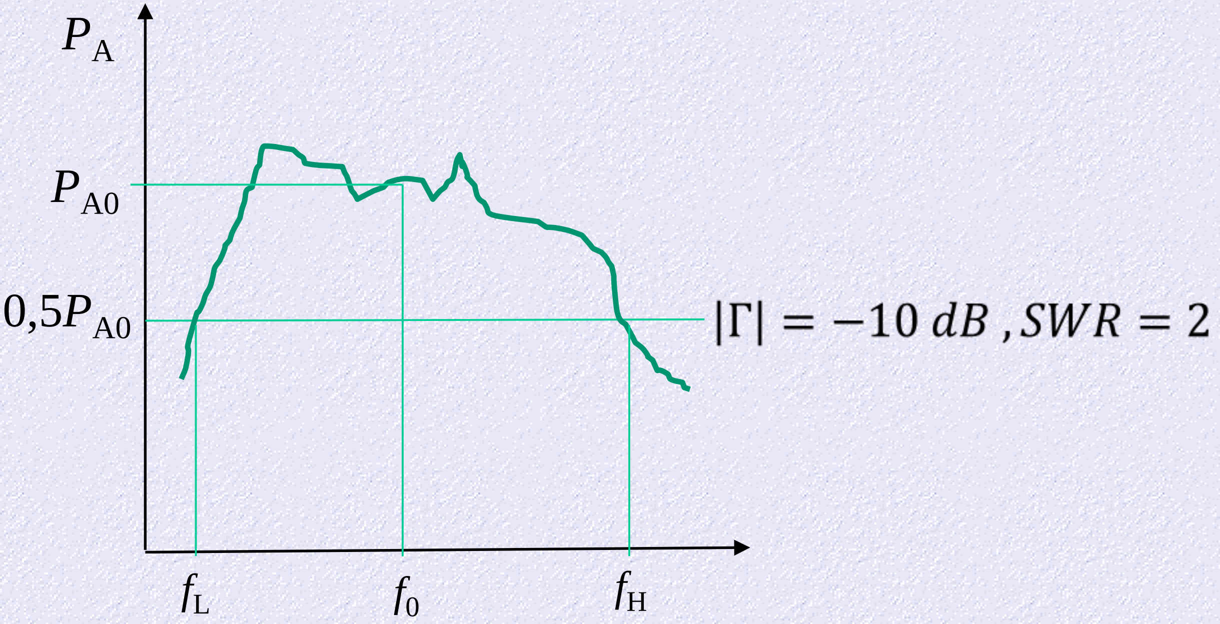
Standing wave ratio SWR

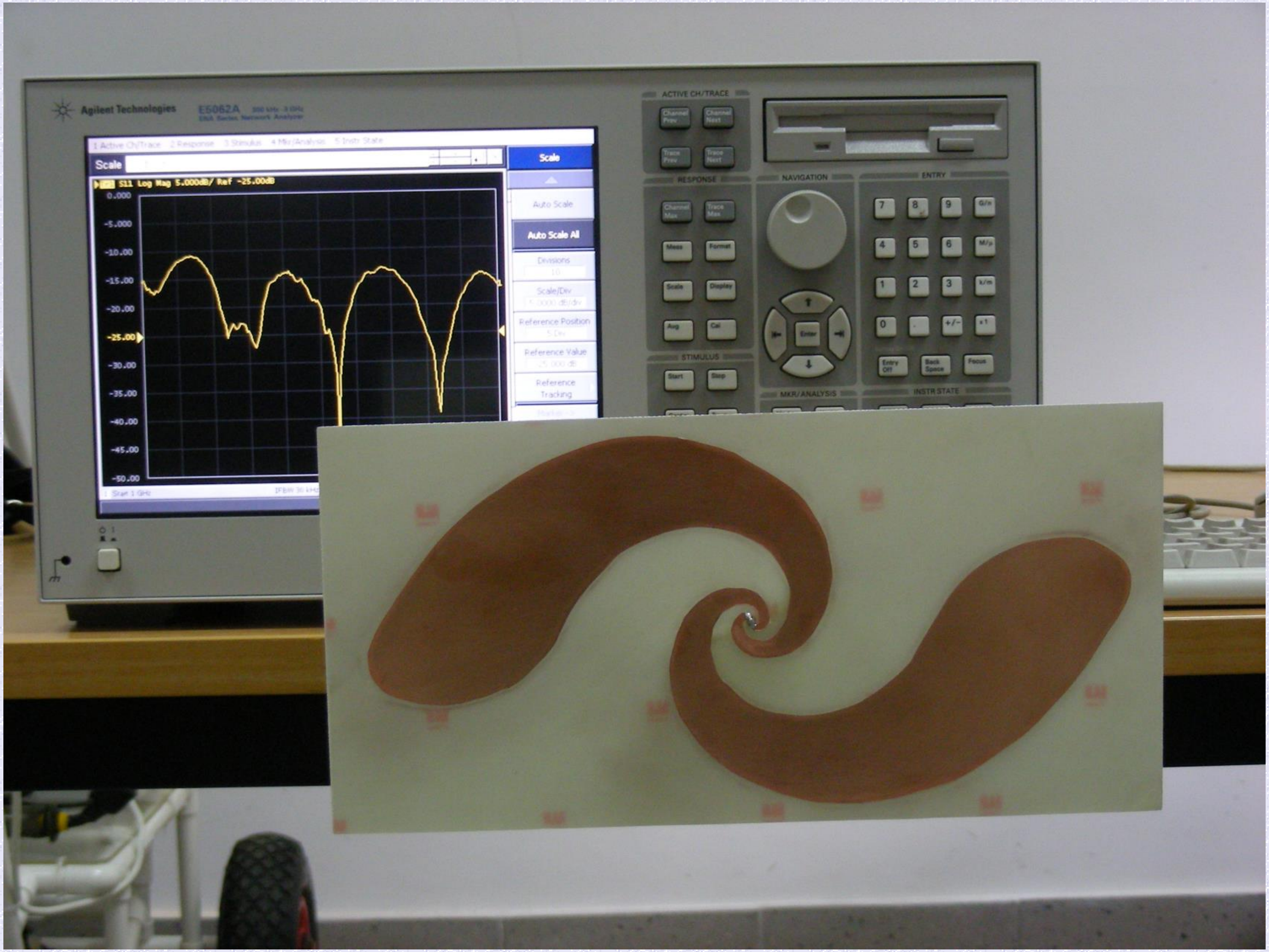
$$\mathrm{VSWR} = \mathrm{SVR} = \frac{|u_{max}|}{|u_{min}|} = \frac{1 + |\Gamma|}{1 - |\Gamma|} \qquad \mathrm{VSWR} \in < 1; \infty)$$

$$\mathrm{SWR} = \frac{1 + \sqrt{P_{refl}/P_{in}}}{1 - \sqrt{P_{refl}/Pi_{n}}}$$

Antenna bandwidth

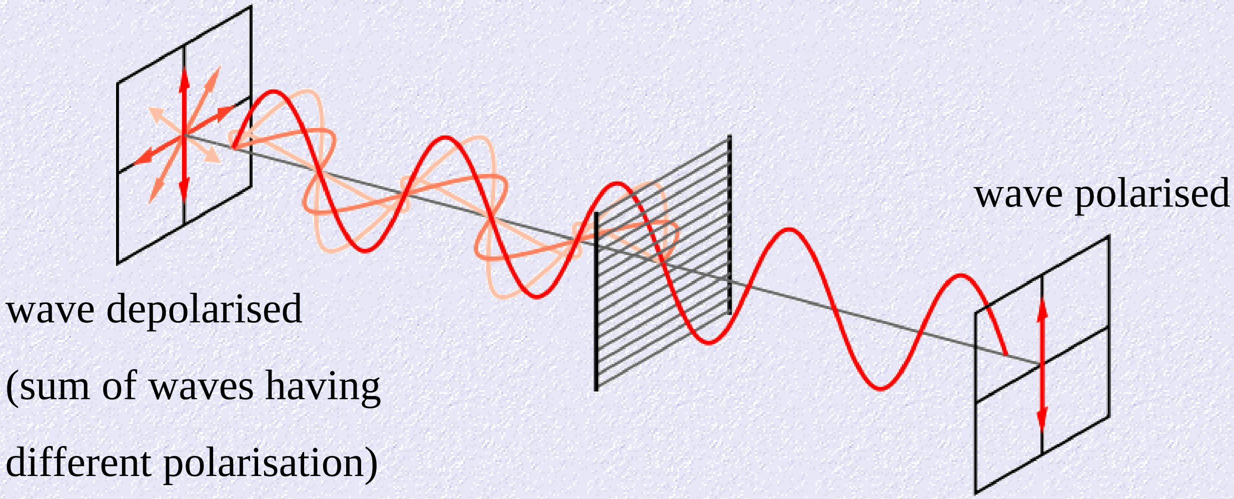
Difference betwin highest and lowest frequency for which the radiation power decreases to the half of their value at the center frequency

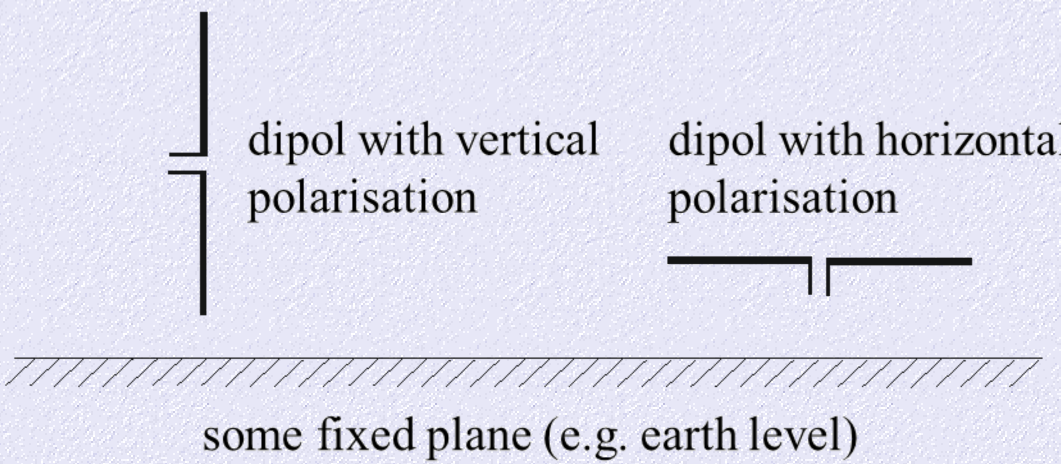



Agilent Technologies
E5062A
Scale
S11 Log Mag 5.000dB/ Ref -25.00dB
0.000
-5.000
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
-50.00
Auto Scale
Auto Scale All
Divisions
Scale/Div
Reference Position
Reference Value
Reference Tracking
ACTIVE CH/TRACE
RESPONSE
NAVIGATION
ENTRY
STIMULUS
MKR/ANALYSIS
INSTR STATE

polarisation

Is determined by plane and direction of vibration of electric field vector

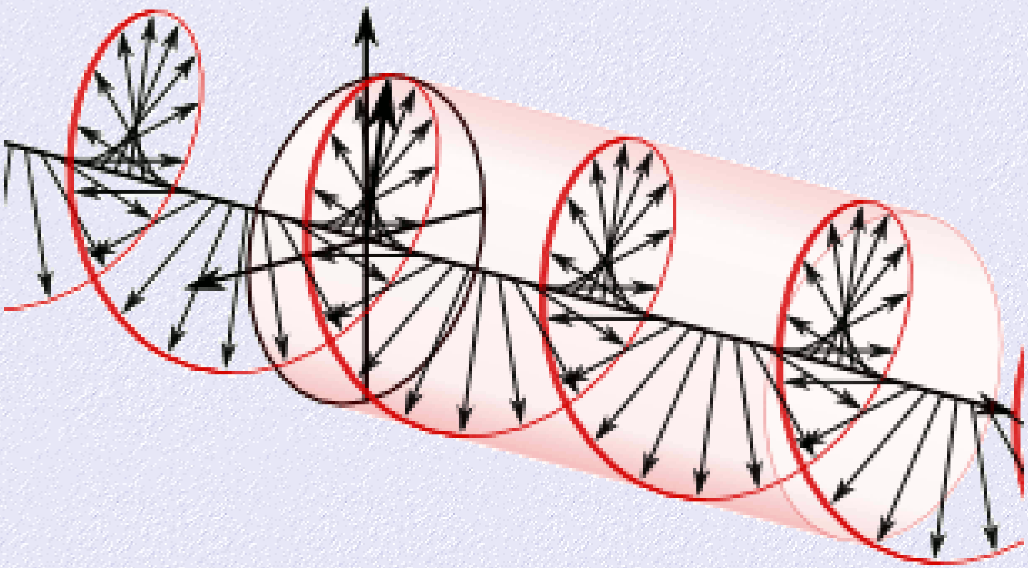




When the direction of electric field vevtor vibration is fixed then wave has linear polarisation

In the other case polarisation is nonlinear.

Special case of nonlinear polarisation is eliptical polarisation left- or right-handed



Special case of eliptical polarisation is circular polarisation

Antenna aperture

Area, oriented perpendicular to the direction of an incoming electromagnetic wave, which would intercept the same amount of power from that wave as is produced by the receiving antenna.

Effective area of antenna

Ratio of power delivered to the receiver to incident power density

Gain

Power radiated in desired direction

$$G = 10\log\frac{P_{\mathrm{R}}}{P_{\mathrm{Riso}}} \quad [\mathrm{dBi}]$$

Power radiated by isotropic antenna

Isotropic antenna has gain equal to 0 dBi

Energetic gain

Gain with losses

For typical antennas gain reaches a dozen or so dBi

For half-wave dipole G = 2,15 dBi

It is important how to take the gain value

2 examples

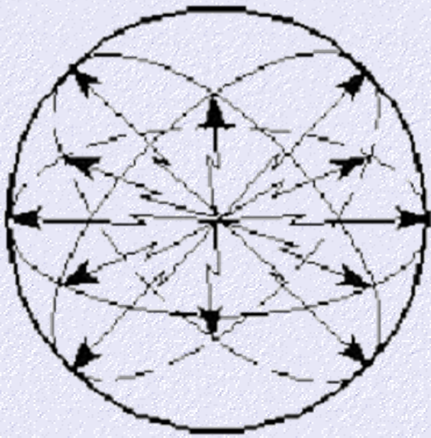
Antenna has gain related to dipole G = 3 dBd what is the gain related to izotropic antenna

3 dBd = 3 dBi + 2,15 dB = 5,15 dBi

Antenna has 6 dBi what is the gain related to dipole?

6 dBi = 6 dBd - 2,15 dB = 3,85 dBi

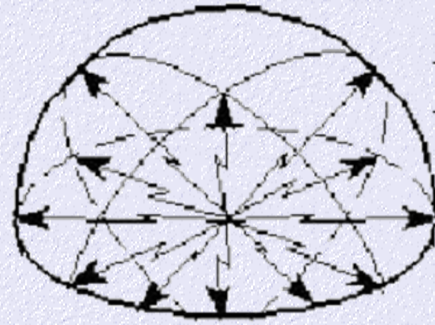
sphere – isotropic source



$$\Pi_i = \frac{P_t}{4\pi R^2}$$

0 dBi

hemisphere

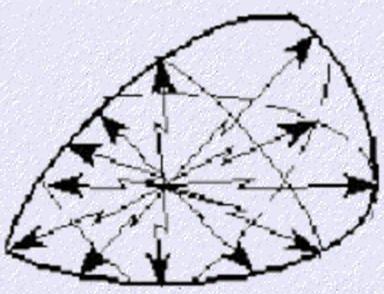


$$\Pi_i = \frac{P_t 2}{4\pi R^2}$$

+3 dBi

¼ sphere

$$\Pi_i = \frac{P_t 4}{4\pi R^2}$$



+6 dBi

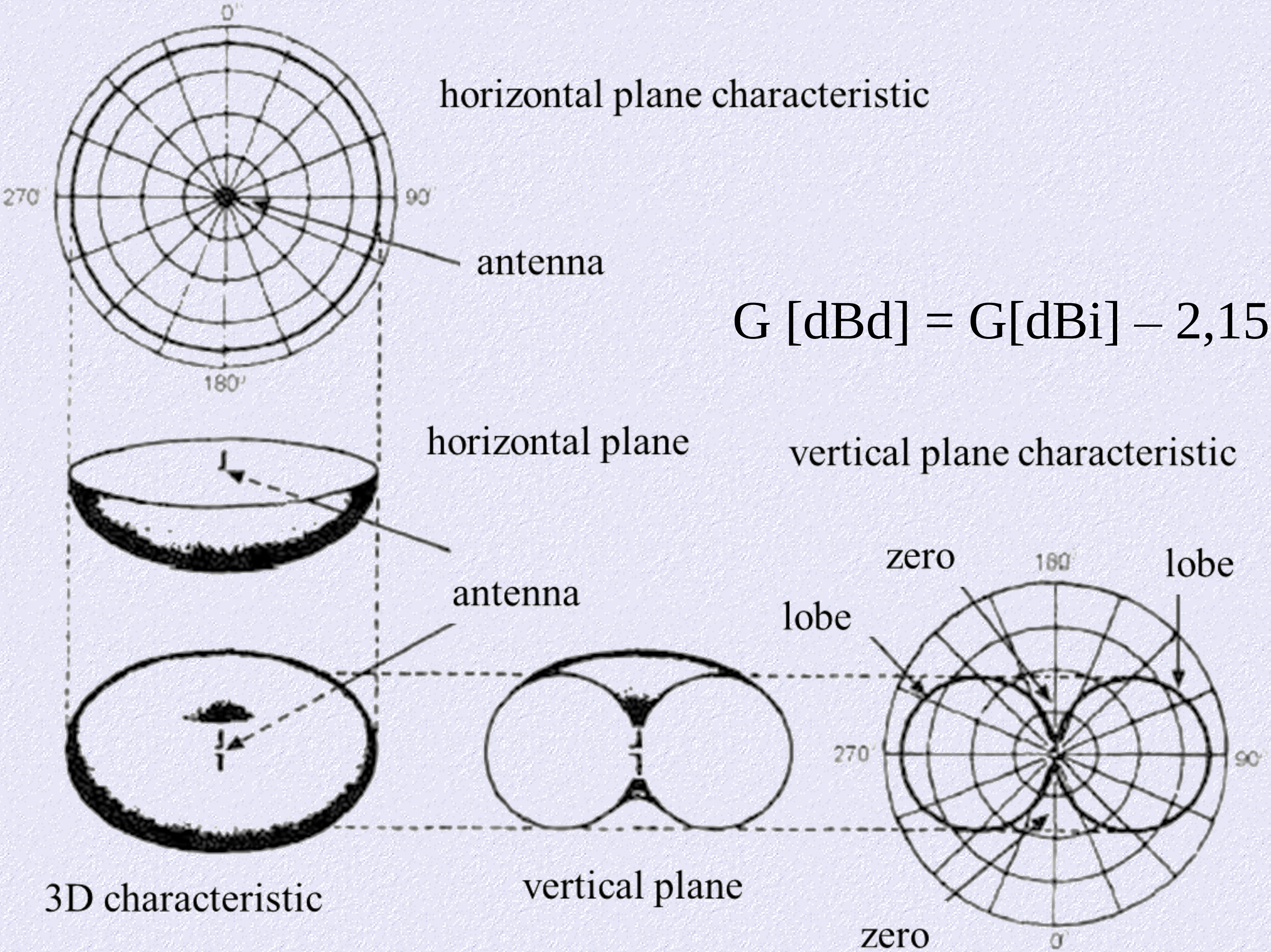
1,5° beam

$$\Pi_i = \frac{P_t \cdot 18334}{4\pi R^2}$$

+43 dBi

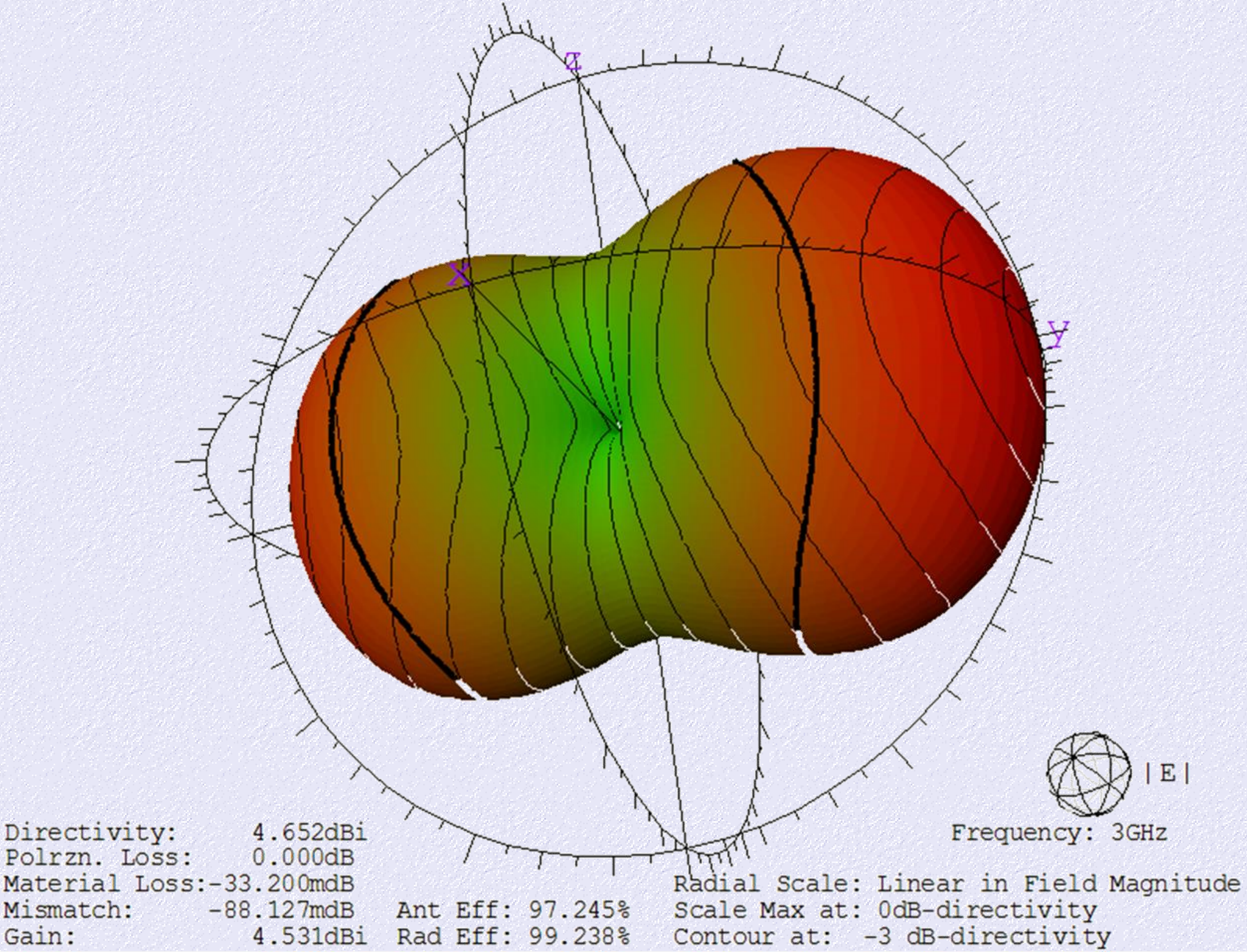
Radiation characteristics

Example for half-wave diplole



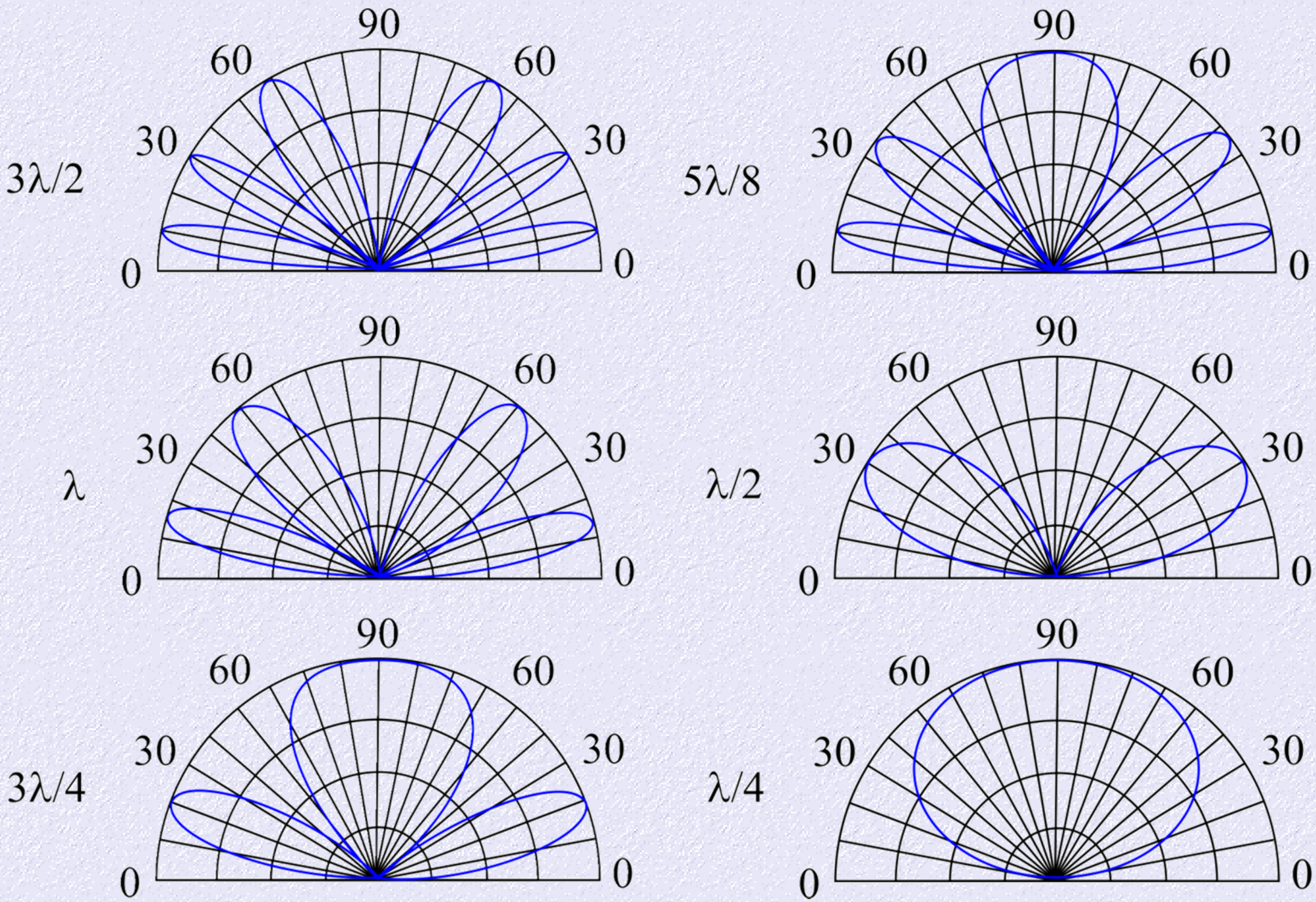
$$G\ [dBd] = G[dBi] - 2{,}15\ [dB]$$

Example of radiation characteristic at 3 GHz



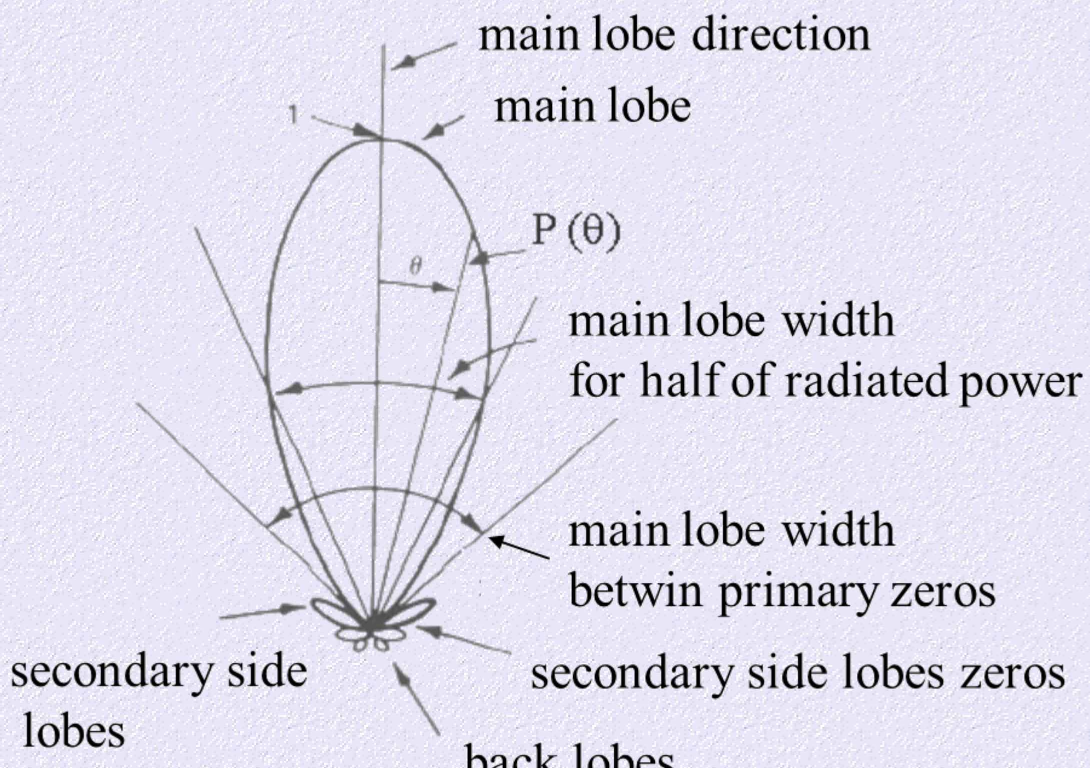
Radiation charakteristic depends on antenna distance from reflective plane

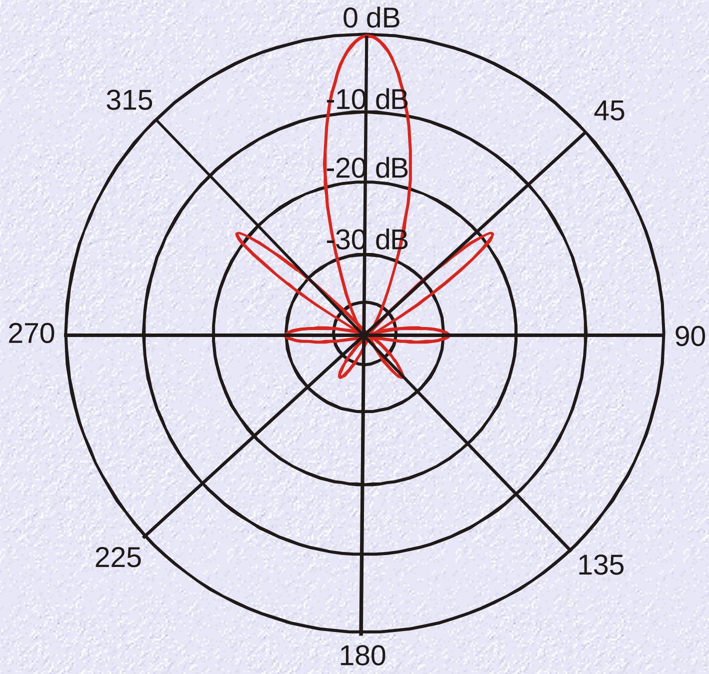
For dipole hanged over ground plane at distance form centre:

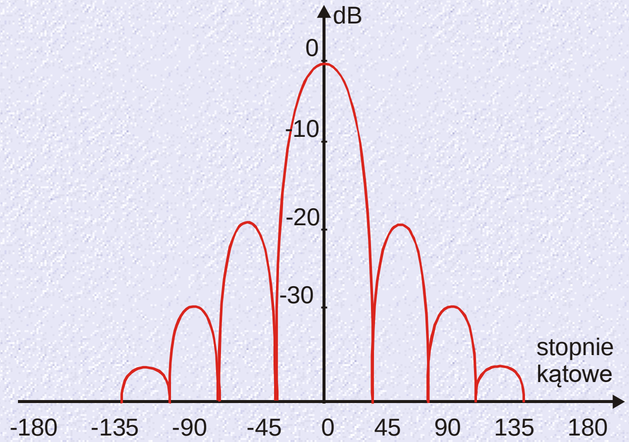


The phenomena is very important from telecommunication point of view

Main and side lobes of radiation characteristic







Real charactaristic are commonly asymetric