Dipole Antennas

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Infinitesimal Dipole

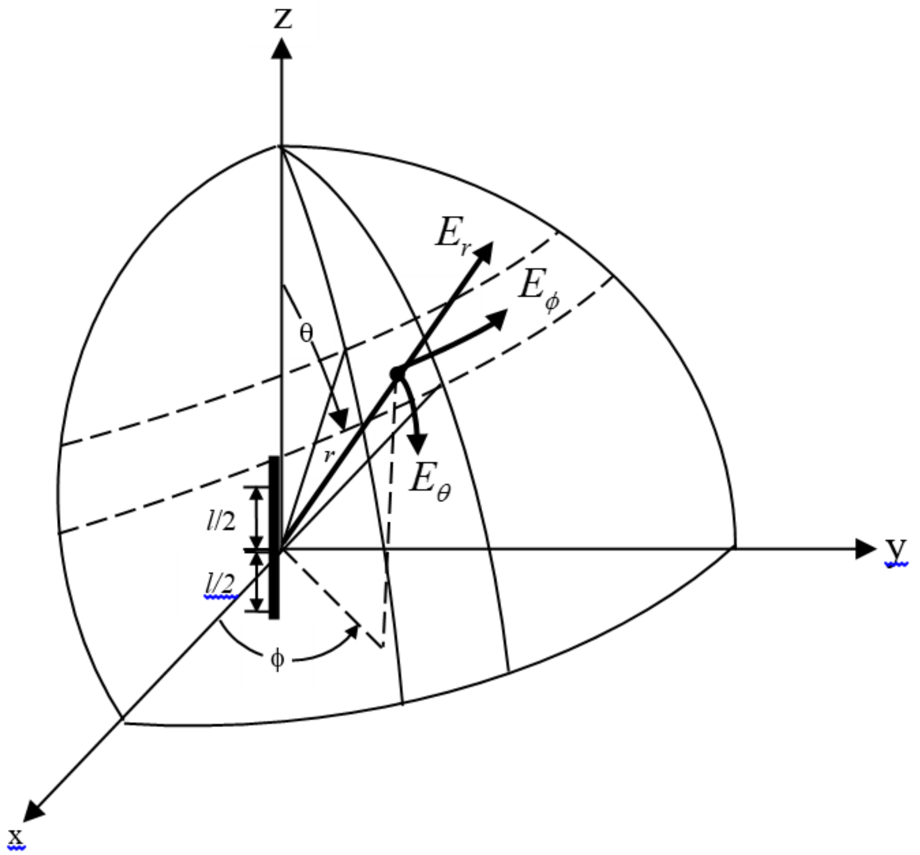
An infinitesimally small current element is called the Hertz Dipole (Length L< λ/50)

Assume an infinitesimal current element of length dl carrying an alternating current I_o. The instantaneous current is

$$\boxed{i(t) = I_o e^{jwt} \hat{i}_z}$$

$$\boxed{A = A_z \hat{z} = \frac{\mu}{4\pi} I_o dl \frac{e^{-jkr}}{r} e^{jwt} \hat{z}}$$

where, $k = \frac{2\pi}{\lambda}$



Dipole and its field components in spherical polar co-ordinate

Uniform Current –Magnetic Vector Potential

$$\underline{A} = \hat{a}_z A_z = \hat{a}_z \frac{\mu I_o \ell}{4\pi r} e^{-jkr}$$

$$A_r = A_z \cos\theta = \frac{\mu I_o \ell}{4\pi r} \cos\theta \; e^{-jkr}$$

$$A_\theta = -A_z \sin\theta = -\frac{\mu I_o \ell}{4\pi r} \sin\theta \; e^{-jkr}$$

$$A_\phi = 0$$

E and H Fields from Magnetic Vector Potential

$$\underline{H} = \frac{1}{\mu}\nabla \times \underline{A} = \hat{a}_\phi \frac{1}{\mu r}\left[\frac{\partial}{\partial r}(rA_\theta) - \frac{\partial A_r}{\partial \theta}\right]$$

$$\underline{E} = -j\omega \underline{A} - j\frac{1}{\omega\mu\varepsilon}\nabla(\nabla \cdot \underline{A})$$

$$P = \frac{1}{2}\iint_S \underline{E} \times \underline{H}^* \cdot d\underline{s}$$

Uniform Current – E and H Fields

$$E_r = \eta \frac{I_o \ell}{2\pi r^2} \cos\theta \left[1 + \frac{1}{jkr} \right] e^{-jkr}$$

$$E_\theta = j\eta \frac{k I_o \ell}{4\pi r} \sin\theta \left[1 + \frac{1}{jkr} - \frac{1}{(kr)^2} \right] e^{-jkr}$$

$$E_\phi = H_r = H_\theta = 0$$

$$H_\phi = j \frac{k I_o \ell}{4\pi r} \left[1 + \frac{1}{jkr} \right] \sin\theta \, e^{-jkr}$$

Uniform Current – Near and Far Fields

Near Field Region

$$r \ll \frac{\lambda}{2\pi} \qquad r < \frac{\lambda}{6}$$

Near Reactive Field Region

$$\frac{\lambda}{6} < r < \frac{2d^2}{\lambda}$$

Near Radiative Field Region

Far Field Region

$$r \gg \frac{\lambda}{2\pi} \qquad r > \frac{2d^2}{\lambda}$$

where d is the maximum dimension of the antenna

Uniform Current - Radiation Pattern

Far Field Region (kr>>1)

$$E_\theta = j\eta \frac{kI_o l}{4\pi r}\sin\theta$$

$$H_\phi = j\frac{kI_o l}{4\pi r}\sin\theta$$

$$\frac{E_\theta}{H_\phi} = \eta = 120\pi$$

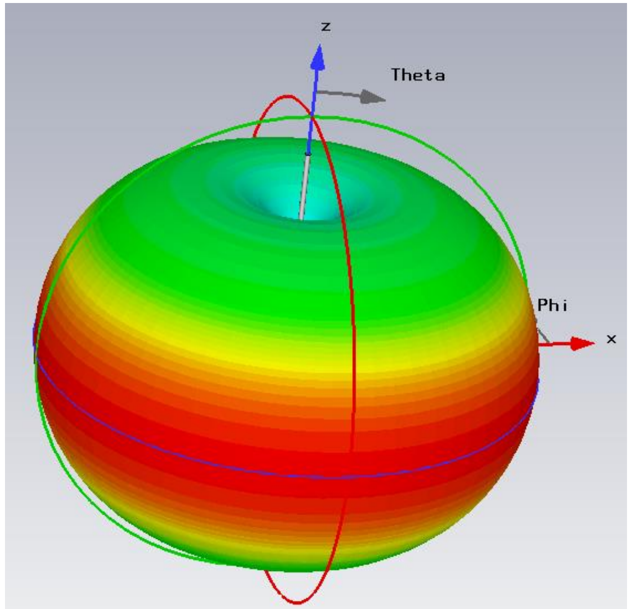
Impedance of free-space

$$R_r = 80\pi^2\left(\frac{l}{\lambda}\right)^2$$

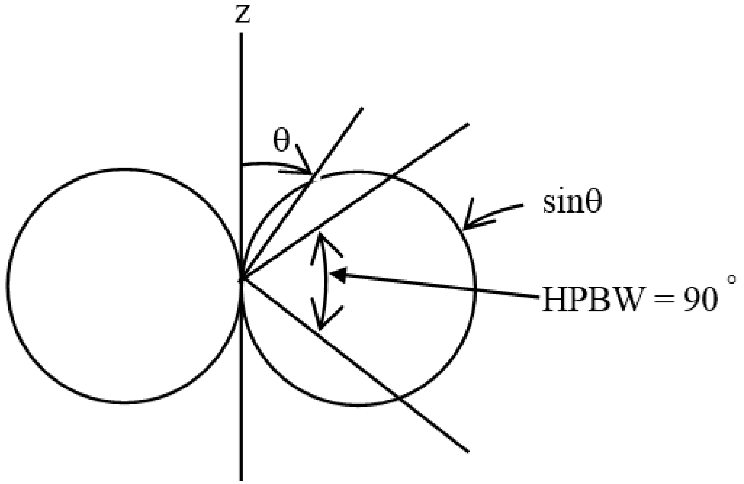
$$E_r \simeq E_\phi = H_r = H_\theta = 0$$

Directivity

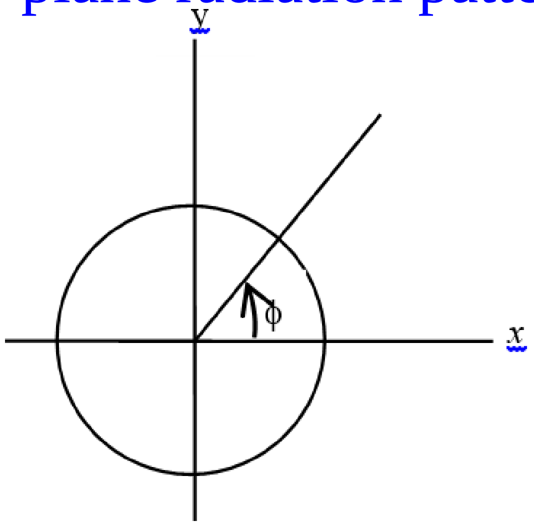
$$D_0 = 4\pi\frac{U_{max}}{P_{rad}} = \frac{3}{2}$$



3-D radiation pattern



E-plane radiation pattern

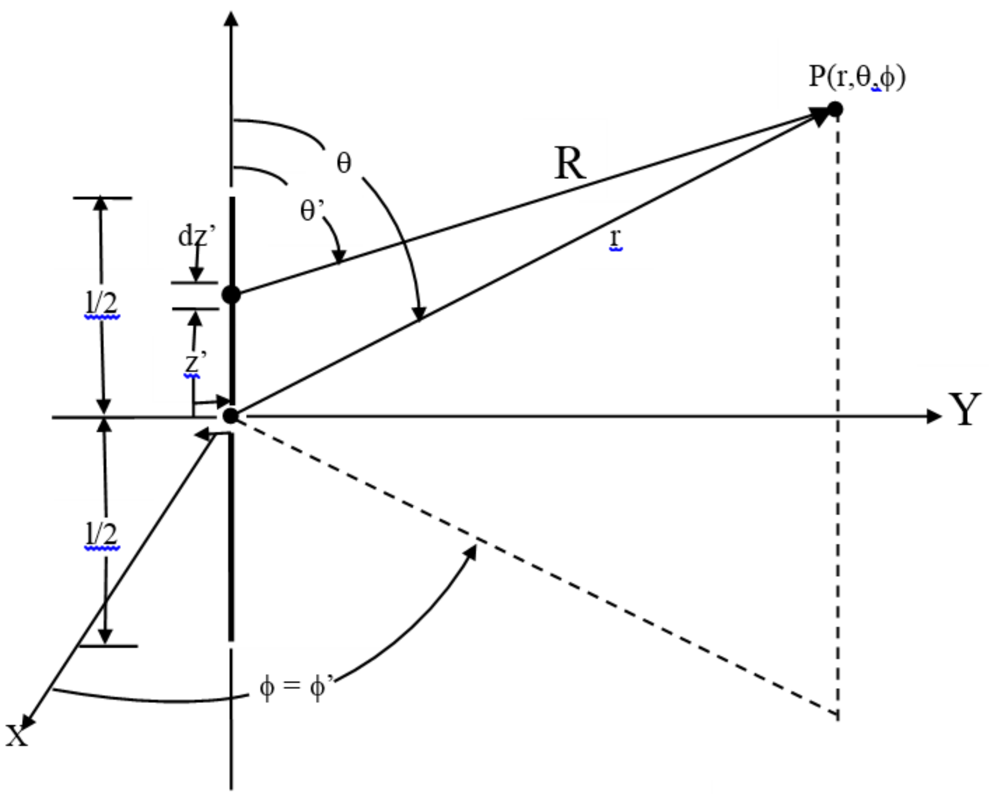


H-plane radiation pattern

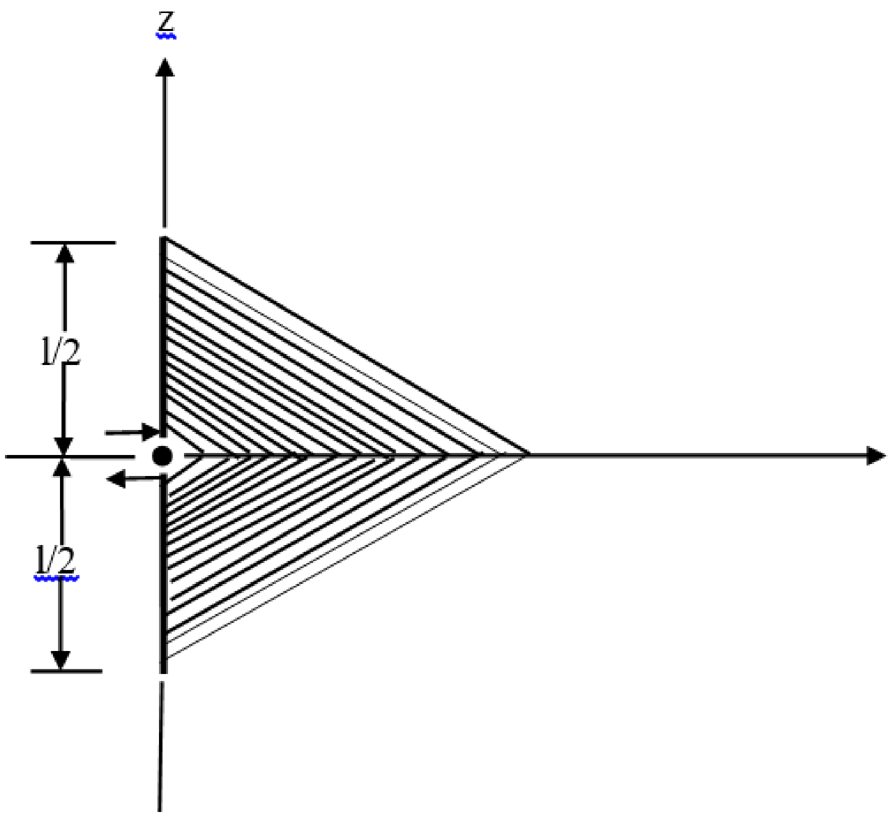
Note : Infinitesimal antenna is not an efficient radiator

Small Dipole Antenna

A current element whose length is $\lambda/50 < l \leq \lambda/10$ is called small dipole antenna



A small dipole Antenna



Approximate Triangular Current distribution

Small Dipole – Radiation Resistance

Small dipole current distribution

$$I_e(x', y', z') = \begin{cases} \hat{a}_z I_0 \left(1 - \dfrac{2}{l} z'\right), & 0 \le z' \le l/2 \\ \hat{a}_z I_0 \left(1 + \dfrac{2}{l} z'\right), & -l/2 \le z' \le 0 \end{cases}$$

Small dipole vector potential

$$A(x, y, z) = \frac{\mu}{4\pi} \left[\hat{a}_z \int_{-l/2}^{0} I_0 \left(1 + \frac{2}{l} z'\right) \frac{e^{-jkR}}{R} dz' + \hat{a}_z \int_{0}^{l/2} I_0 \left(1 - \frac{2}{l} z'\right) \frac{e^{-jkR}}{R} dz' \right]$$

Far Field Region (kr>>1)

$$E_\theta \simeq j\eta \frac{k I_0 l e^{-jkr}}{8\pi r} \sin\theta$$

$$E_r \simeq E_\phi = H_r = H_\theta = 0$$

$$H_\phi \simeq j \frac{k I_0 l e^{-jkr}}{8\pi r} \sin\theta$$

$$R_r = \frac{2P_{rad}}{|I_0|^2} = 20\pi^2 \left(\frac{l}{\lambda}\right)^2$$

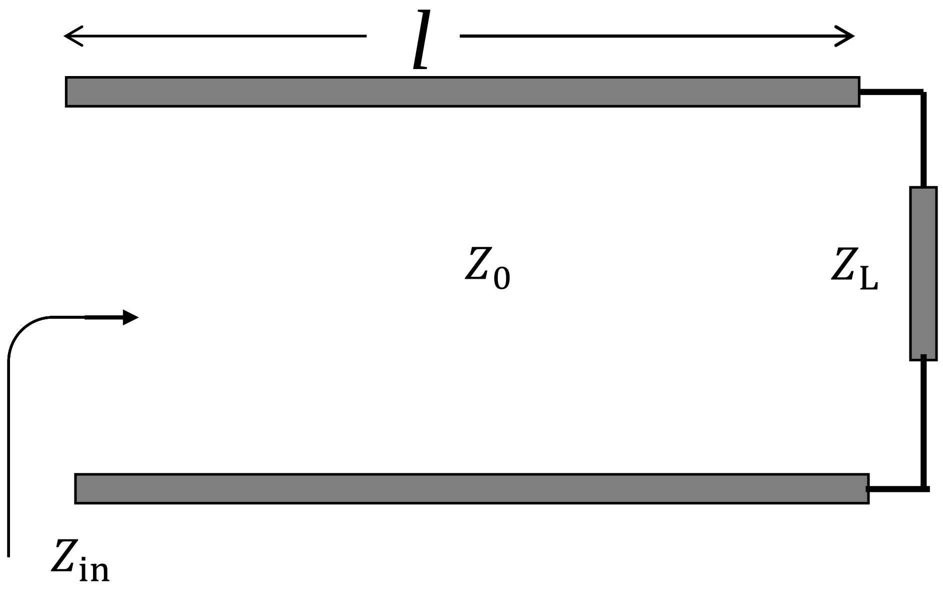
For $l = \lambda / 10$, $R_r = 2\ \Omega$

$l = \lambda / 4$, $R_r = 12.3\ \Omega$

Dipoles also have reactive impedance

Input Impedance of Transmission Line

$$Z_{in} = Z_0 \left[\frac{Z_L + jZ_0 \tan\beta l}{Z_0 + jZ_L \tan\beta l} \right]$$



Case 1: $Z_L = 0, \quad \rightarrow Z_{in} = jZ_0 \tan\beta l$

Case 2: $Z_L = \infty, \quad \rightarrow Z_{in} = \frac{Z_0}{j\tan\beta l}$

Case 3: $Z_L = Z_0, \quad \rightarrow Z_{in} = Z_0$

Where, $\beta = \frac{2\pi}{\lambda}$

$if \;\; l < \frac{\lambda}{4} \rightarrow \tan\beta l = +ve$

$\frac{\lambda}{4} < l < \frac{\lambda}{2} \rightarrow \tan\beta l = -ve$

For Short-circuit, $Z_L = 0$, Z_{in} is inductive, so T-Line represents inductance

Open-circuit, Z_L ∞ , Z_{in} is capacitive, so T-Line represents capacitance

Half wavelength Dipole

Electric and magnetic fields of a half-wavelength dipole

$$E_\theta \simeq j\eta \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right]$$

$$H_\phi \simeq j \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right]$$

Directivity of half-wavelength dipole

$$D_0 = 4\pi \frac{U_{\max}}{P_{rad}} \simeq 1.643$$

D = 2.1 dB

λ/2 Dipole Radiation Resistance

$$R_r = \frac{2P_{rad}}{|I_0|^2} \simeq 73$$

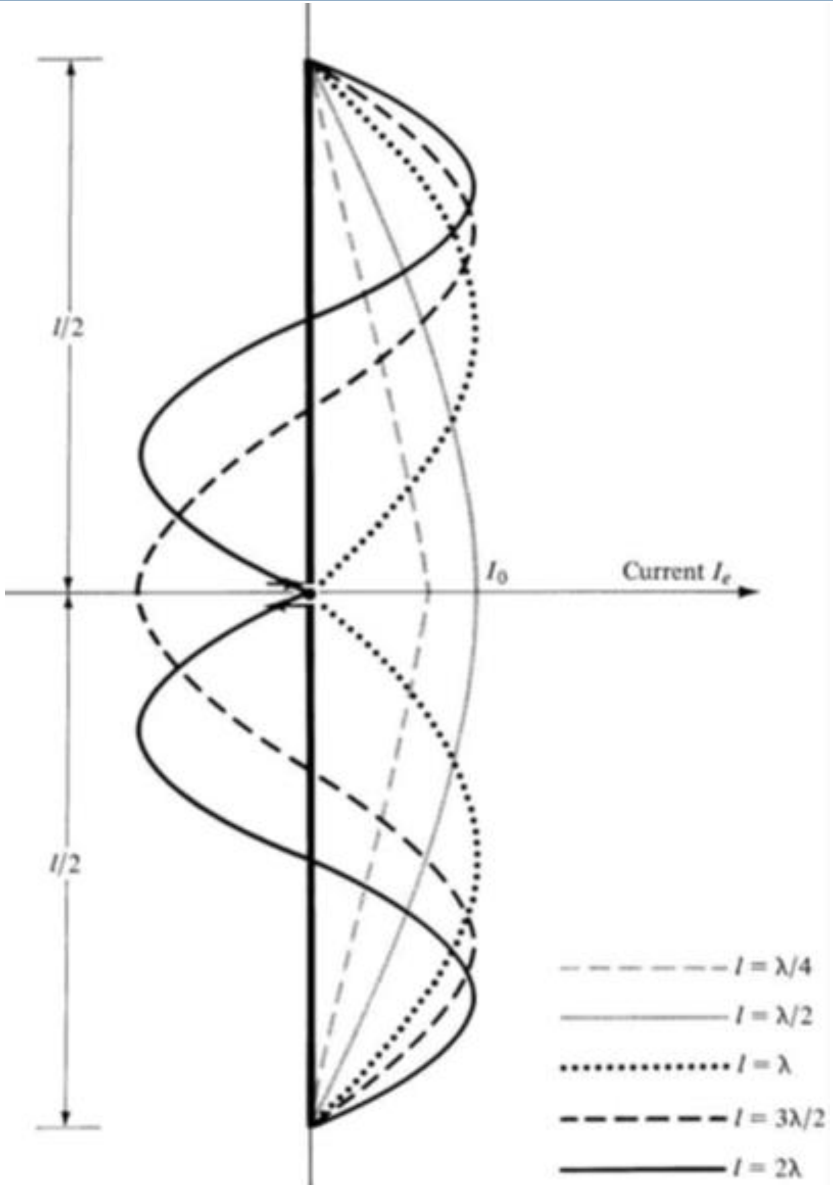
Note: Input impedance for λ/2 dipole is 73+j42.5Ω. To make imaginary part equal to zero, the antenna length is reduced until the input impedance becomes real.

Design of Dipole Antenna

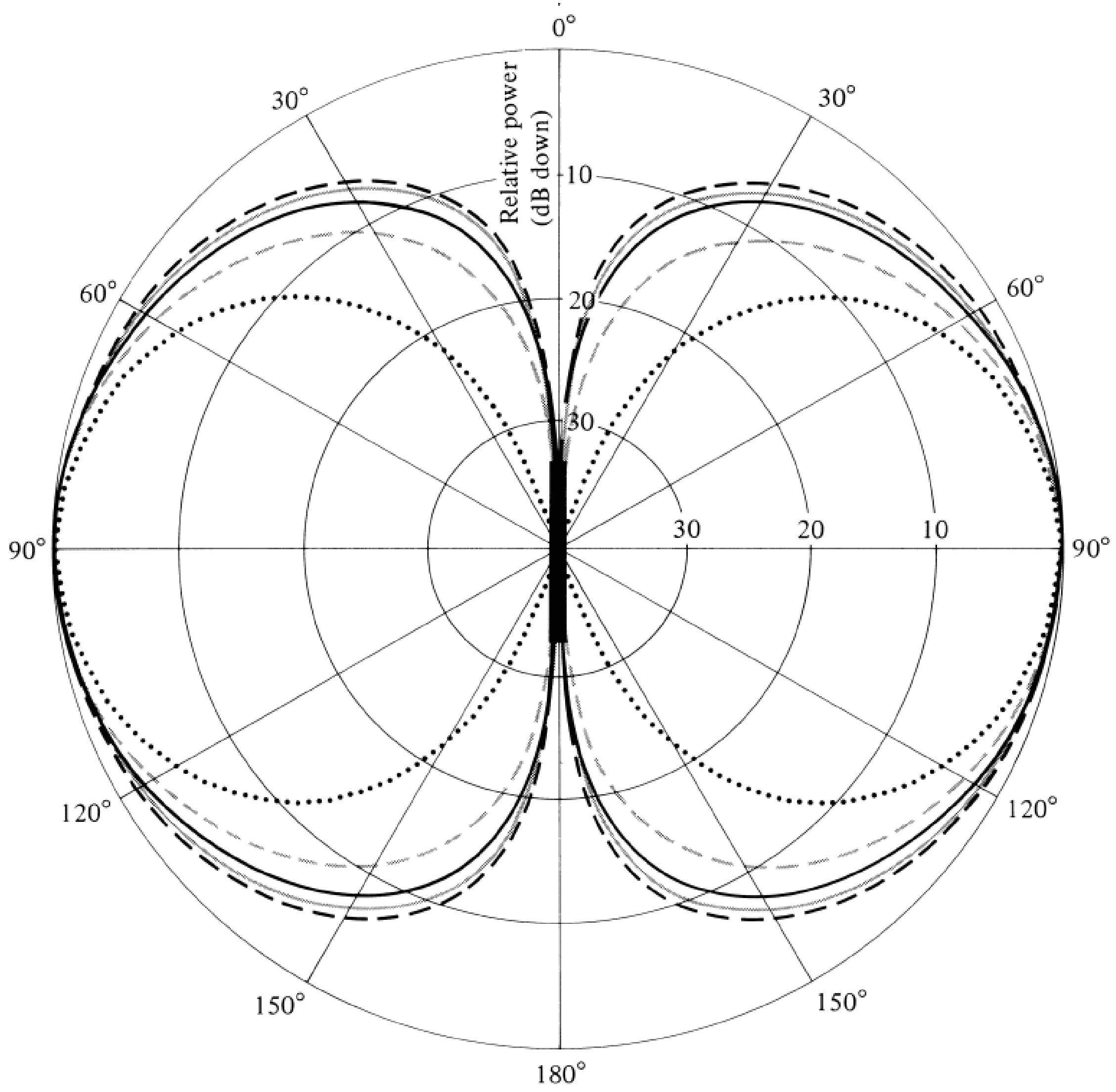
$l + d = 0.48\lambda$, where, d is the diameter of wire and d<λ/10

Real Input impedance is $\leq$ 68Ω.

Current Distribution of Dipole Antenna for Different Lengths



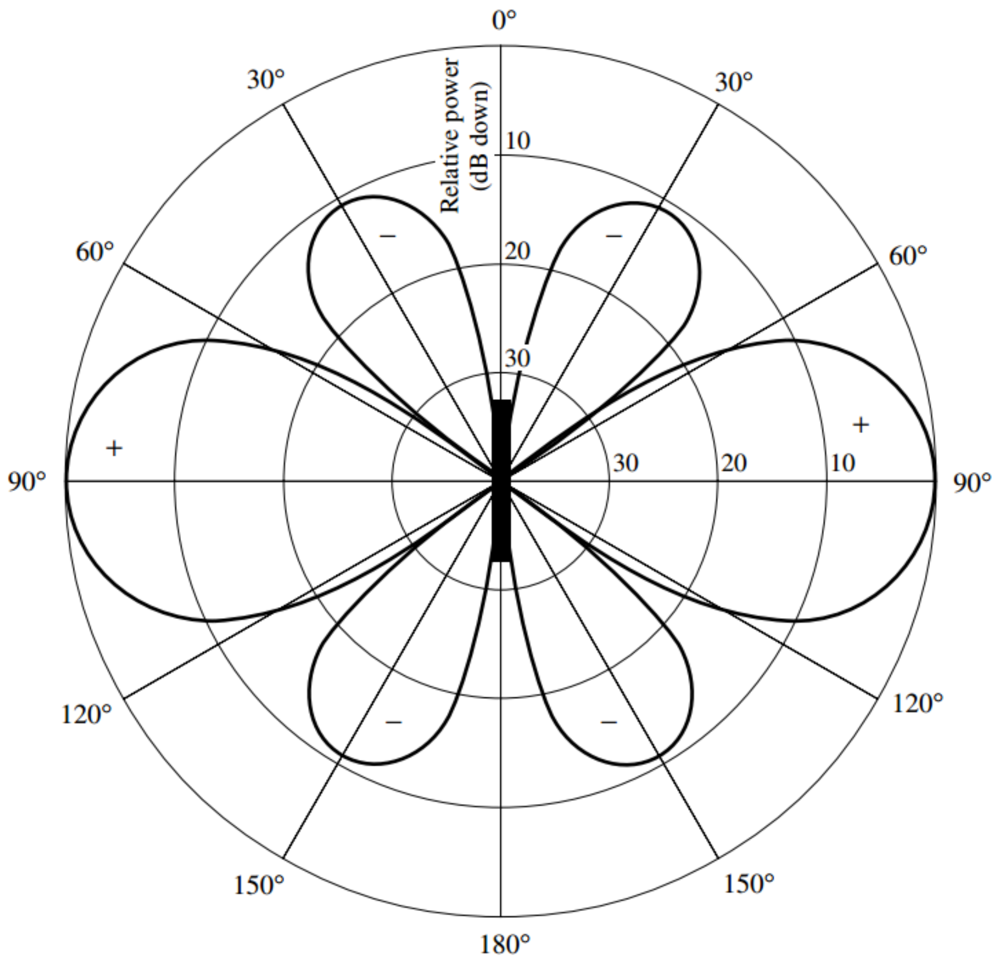
Radiation Pattern of Dipole Antenna for Different Lengths



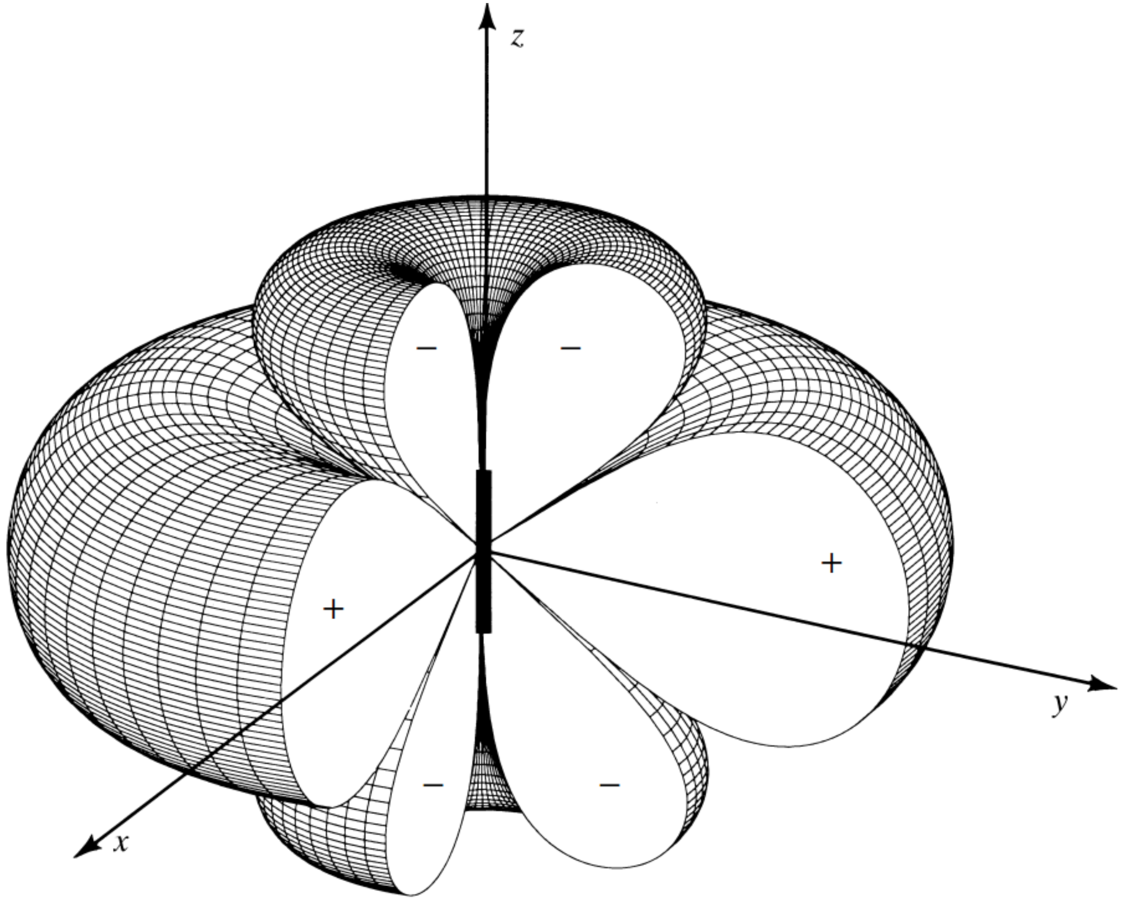
$$E_\theta \simeq j\eta \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{kl}{2}\cos\theta\right) - \cos\left(\frac{kl}{2}\right)}{\sin\theta}\right]$$

- - - - -	$l = \lambda/50$	3-dB beamwidth = 90°
——— (grey)	$l = \lambda/4$	3-dB beamwidth = 87°
———	$l = \lambda/2$	3-dB beamwidth = 78°
- - - (grey)	$l = 3\lambda/4$	3-dB beamwidth = 64°
········	$l = \lambda$	3-dB beamwidth = 47.8°

Dipole Antenna Radiation Pattern for $l = 1.25\lambda$



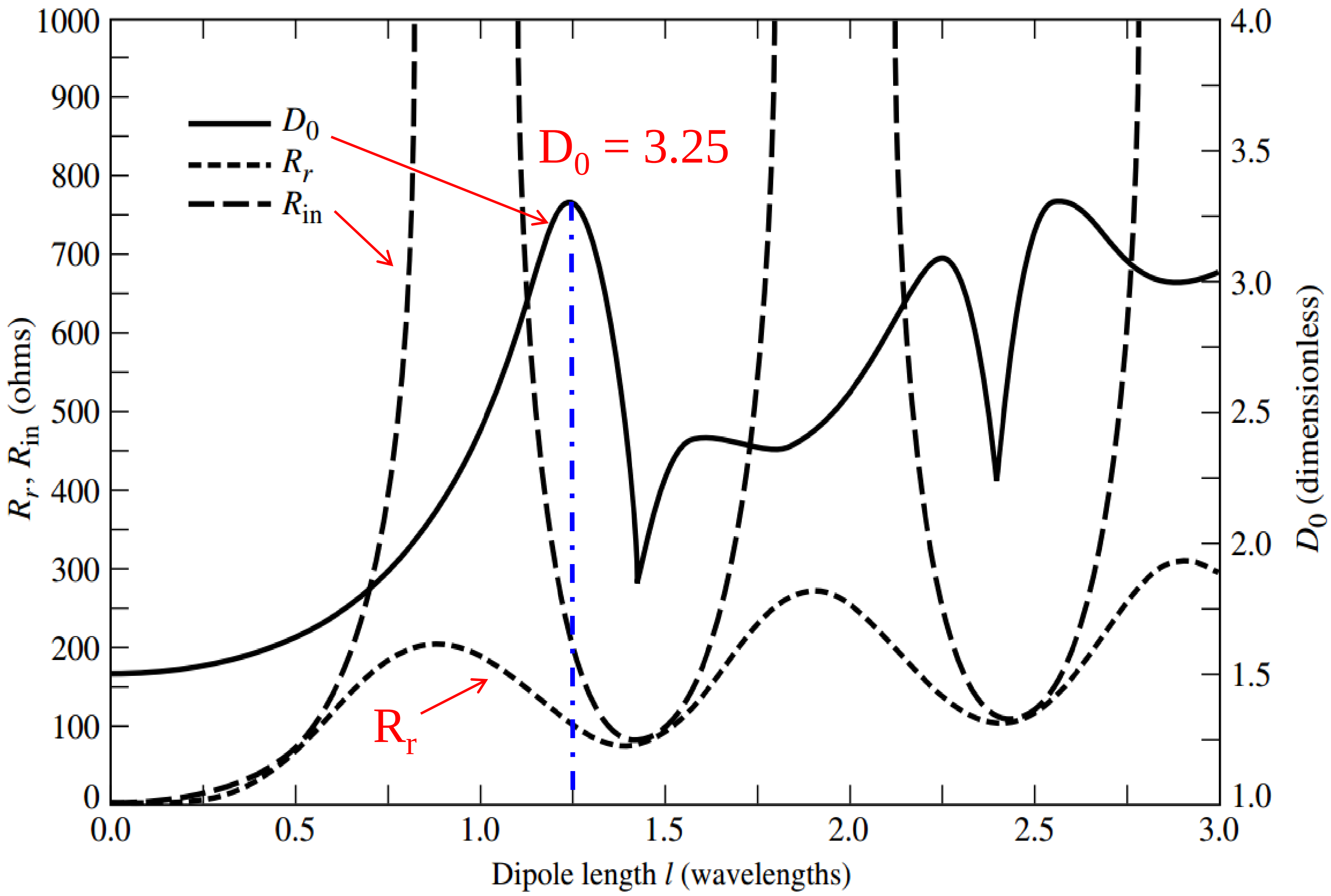
Two Dimensional



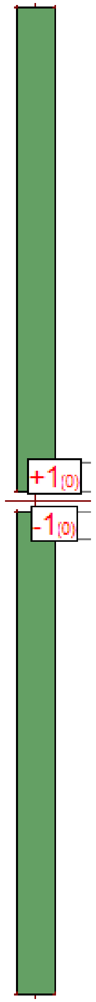
Three Dimensional

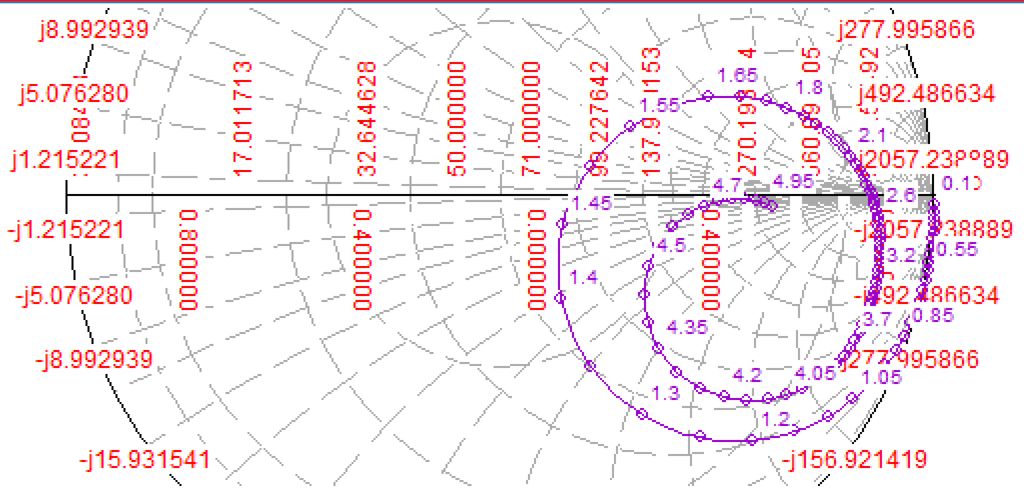
Directivity is maximum for a thin dipole of length $l = 1.25\lambda$

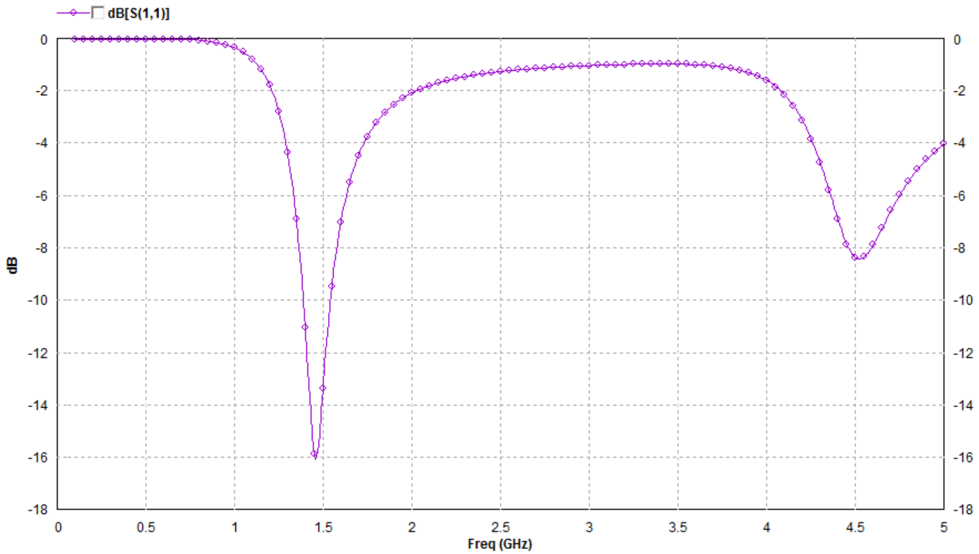
Dipole Antenna Resistance and Directivity



Flat Dipole Antenna





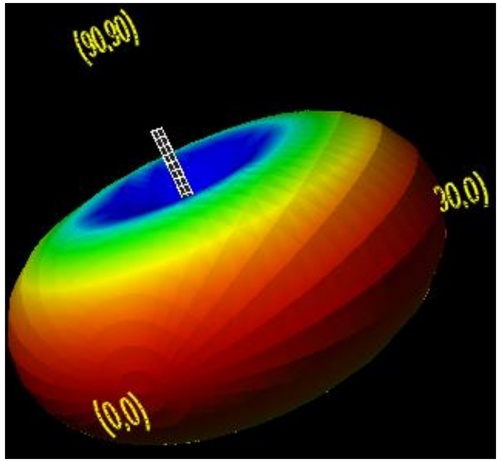


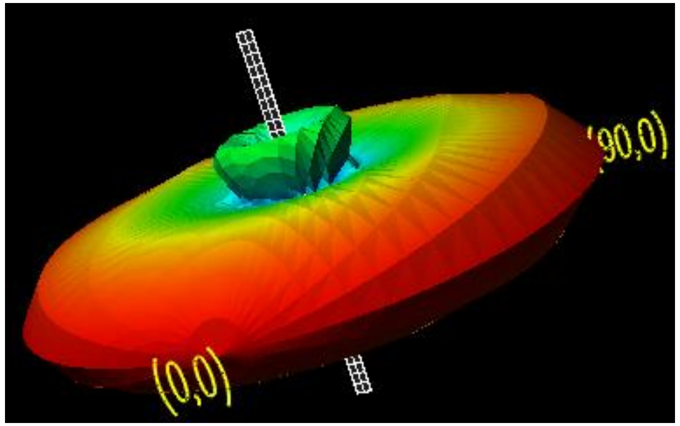
BW for $|S_{11}| \leq 10$ dB is from 1.39 to 1.54 GHz (150 MHz, 10.2%)

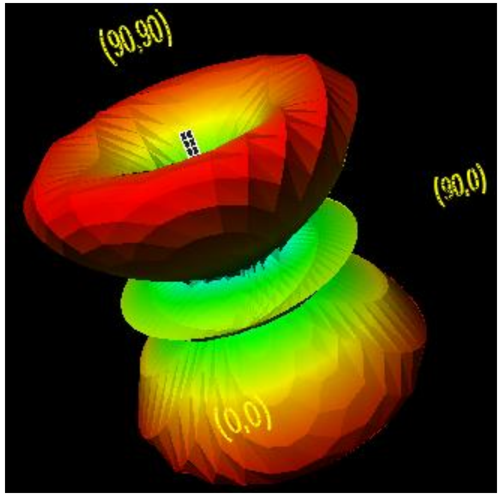
Length of each segment = 50 mm
Width = 4mm, Gap = 2mm

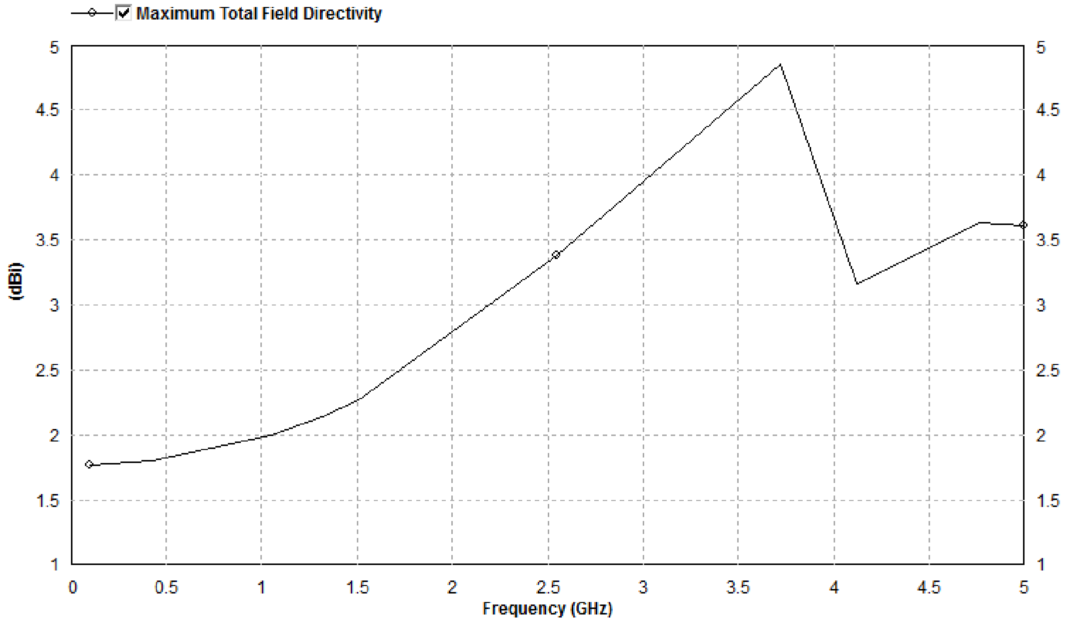
Flat Dipole Antenna Pattern and Directivity

Radiation Pattern at 1.5, 3.75 and 4.5 GHz



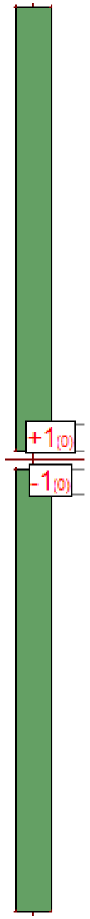


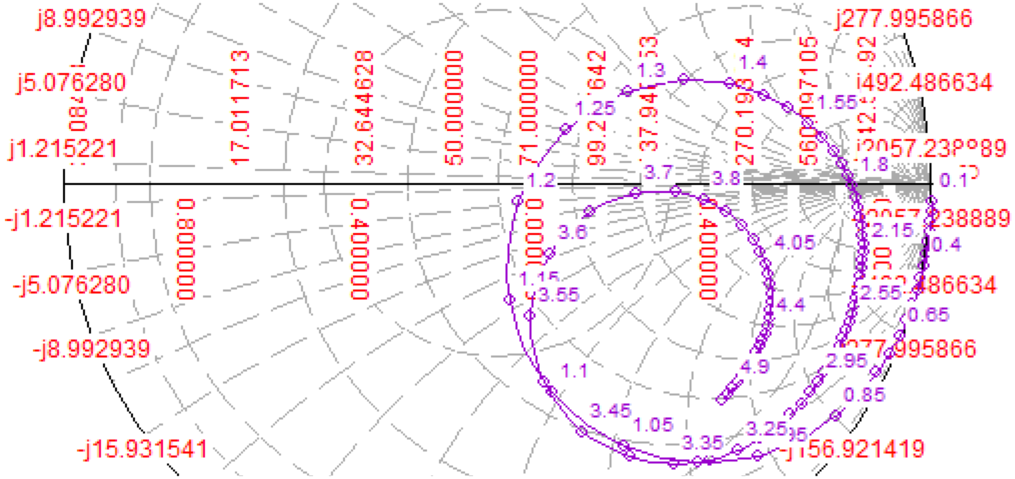


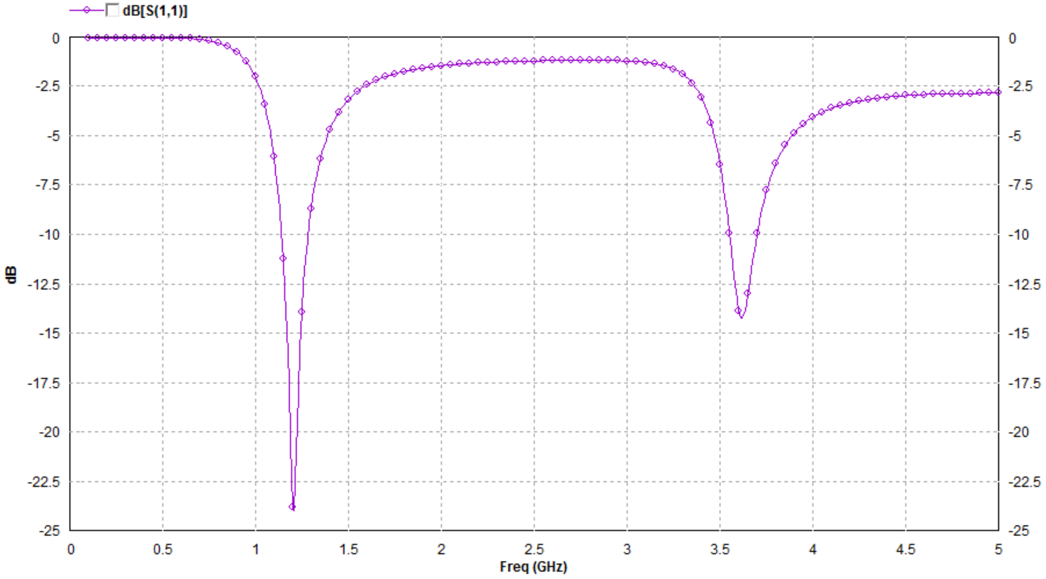


Directivity of 4.8 dB is maximum at 3.75 GHz where length of dipole is approx. 1.25 λ

Printed Dipole Antenna





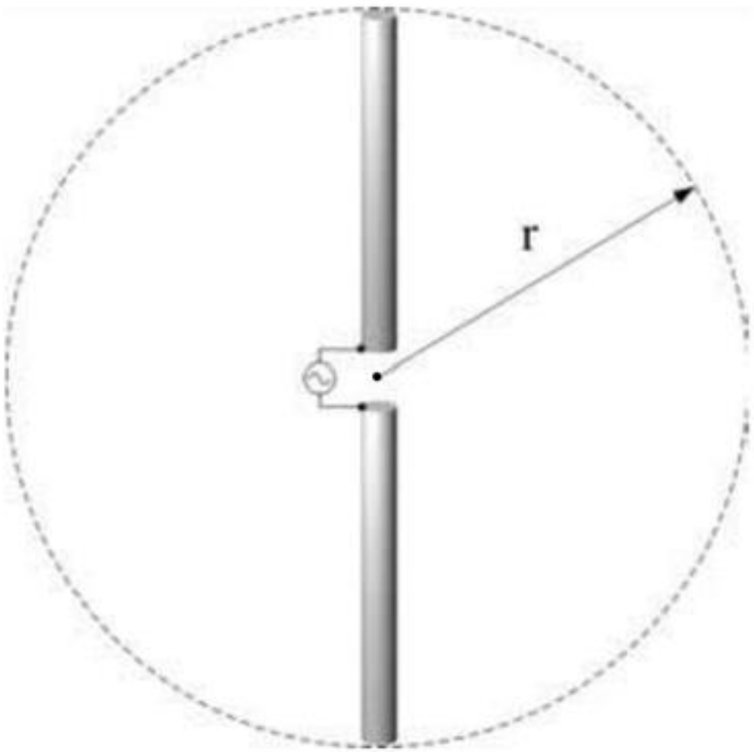


Length of each segment = 50 mm
Width = 4mm, Gap = 2mm
FR4 substrate: ε_r = 4.4, tanδ = 0.02, h = 1.6mm

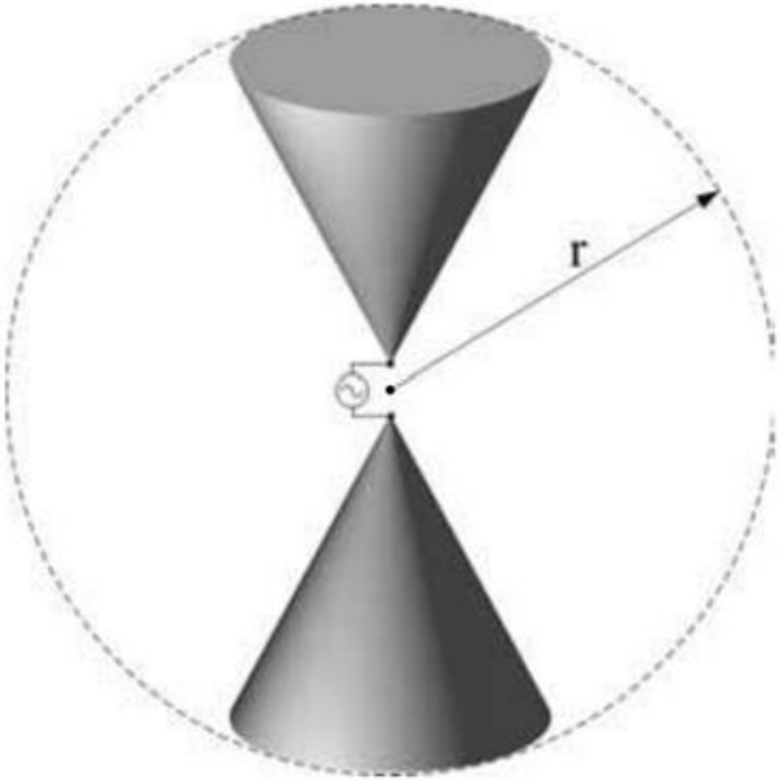
BW = 1.14 to 1.28 GHz (140 MHz, 11.6%)

Broadband Dipole Antenna

Bandwidth of dipole antenna is directly proportional to its diameter



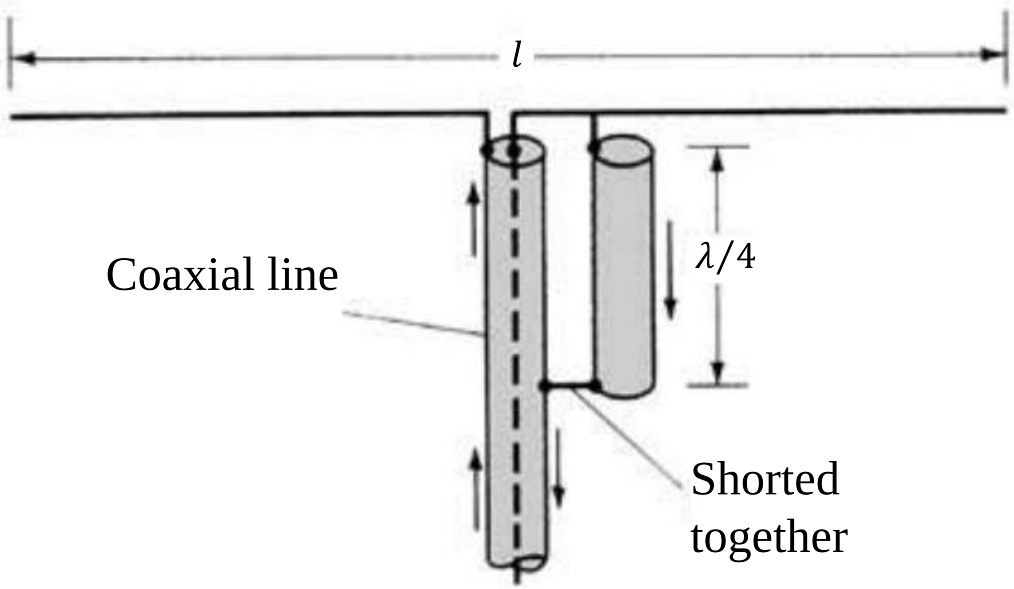
Cylindrical dipole antenna
(can use hollow pipe also)

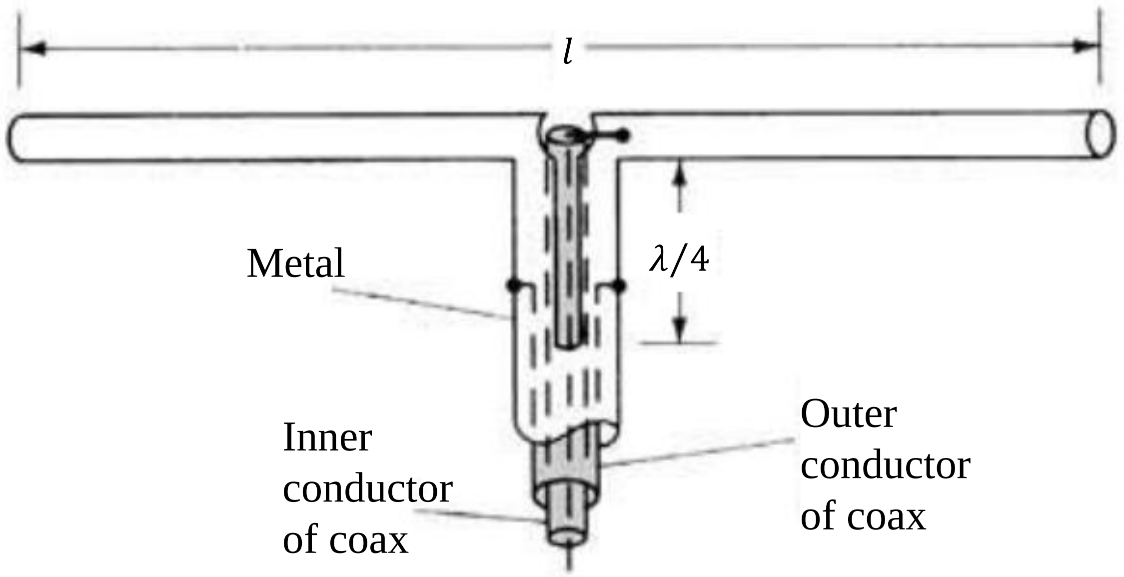


Biconical dipole antenna
(can use wire grid also)

Balun Design

Devices that can be used to balance inherently unbalanced systems by cancelling or choking the outside current, are known as *baluns* (*bal*ance to *un*balance).

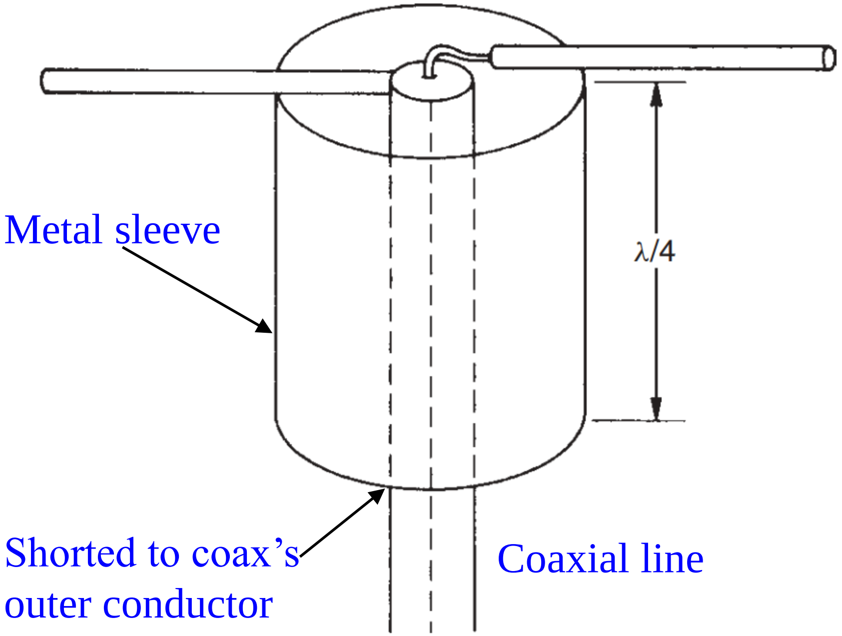




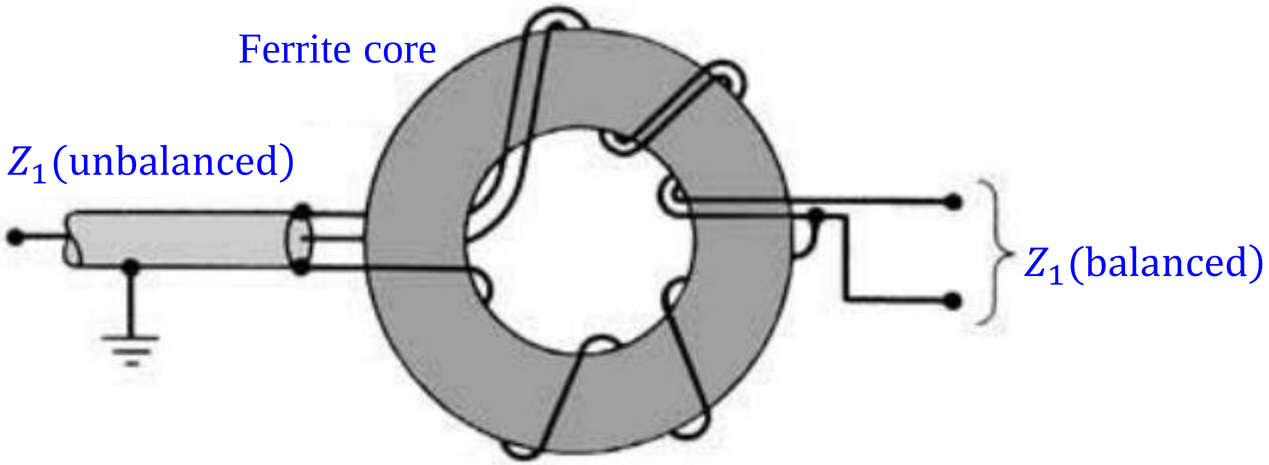
$\lambda/4$ Coaxial Balun (1:1)- Narrow Bandwidth

Balun Design (Contd.)

Ferrite core maintains high impedance levels over a wide frequency range. A good design can provide bandwidths of 10 to 1 whereas coil coaxial baluns can provide bandwidths of 2 or 3 to 1.

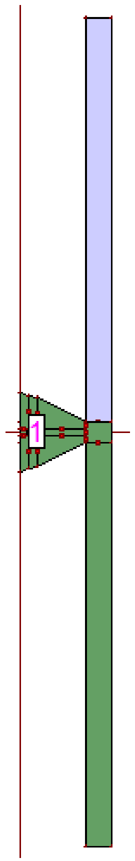


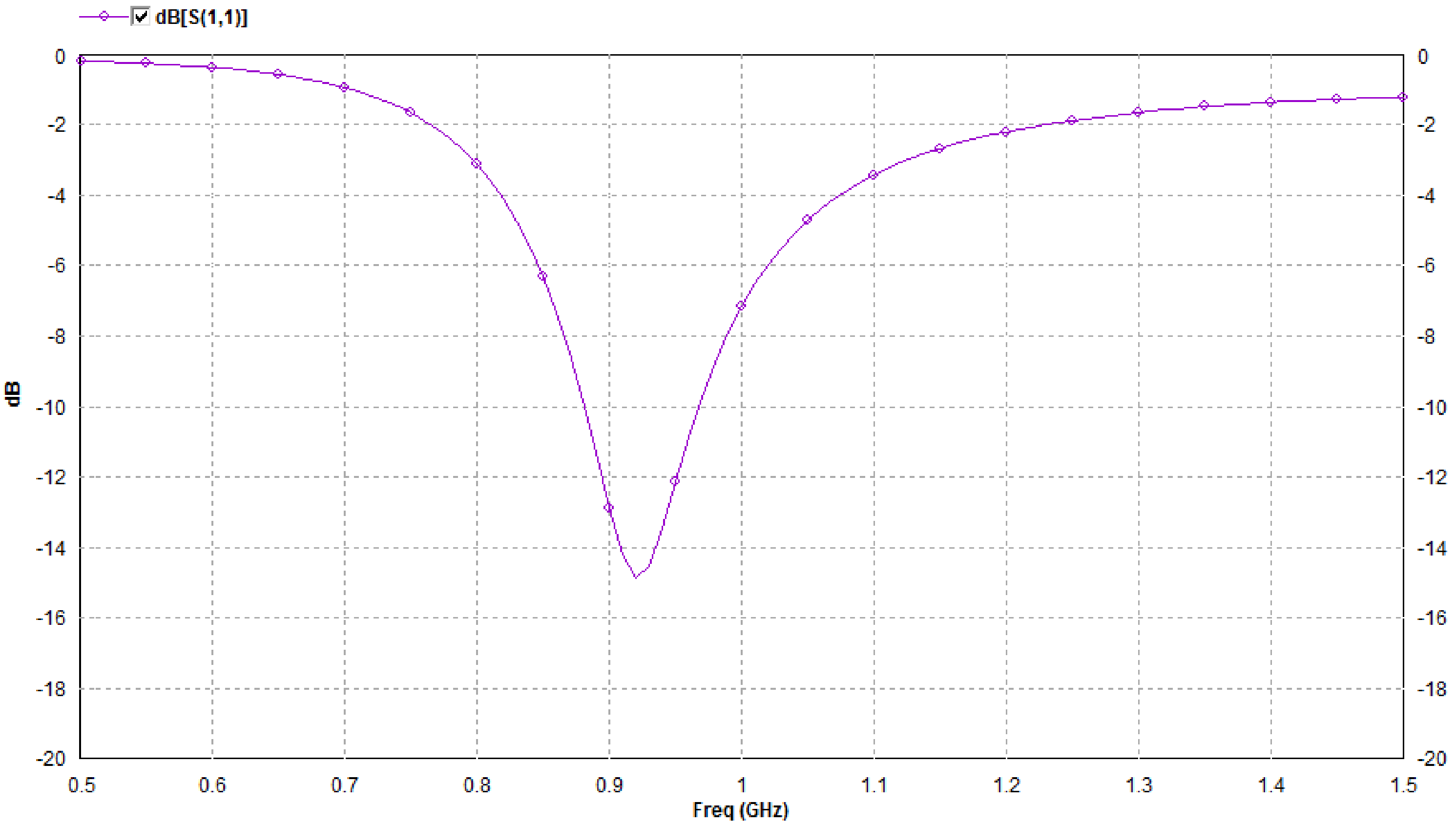
Sleeve or bazooka balun
Narrow BW



Ferrite core balun
Wide BW

Microstrip Balun Dipole Antenna for GSM900

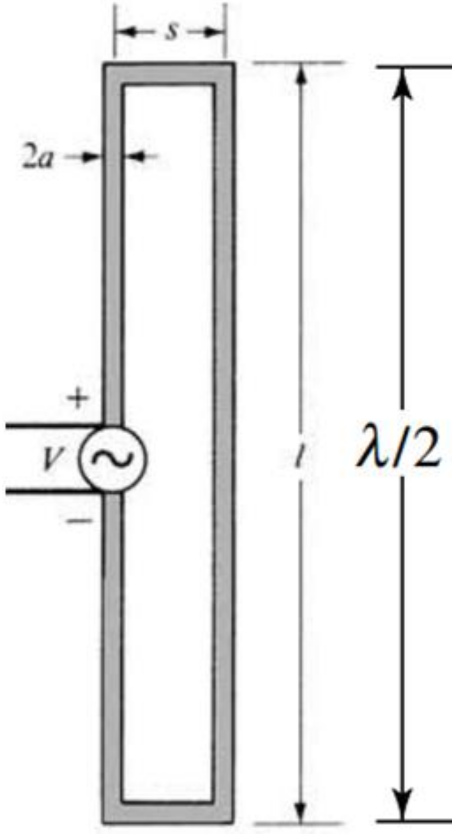




Microstrip Balun Dipole Antenna
L = 127 mm, w = 4 mm
FR4 substrate: $\varepsilon_r = 4.4$, $\tan\delta = 0.02$, h = 1.6mm

BW for $|S_{11}| \leq 10$ dB is from 881 to 967 MHz
(covers GSM900 band of 890 to 960 MHz)

Folded Dipole Antenna



The impedance of the N fold folded dipole is N^2 times greater than that of an isolated dipole of the same length as one of its side.

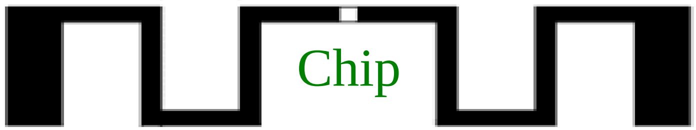
$$Z_{in} = \frac{V}{I_1} \simeq N^2 Z_{11} = N^2 Z_r$$

Impedance for 2-fold dipole antenna is

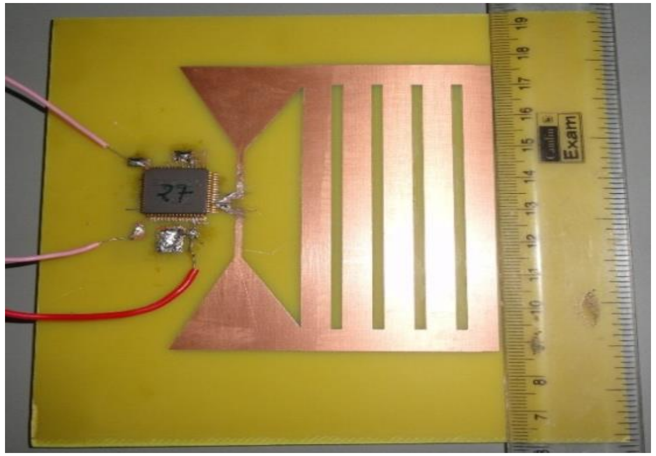
$$Z_{in} = 2^2 Z_r$$
$$Z_{in} = 4Z_r$$

2-fold dipole antennas are used in Yagi-Uda Antennas for TV reception using balanced line of $Z_0 = 300\ \Omega$

Dipole Antenna Applications



Compact Dipole Antenna for RFID



Folded Broadband Dipole Antenna for RF Harvesting

(Triangular shape for broadband and multi-fold gave $Z_{in} = 750\ \Omega$)