# Dipolos (y sus variantes)

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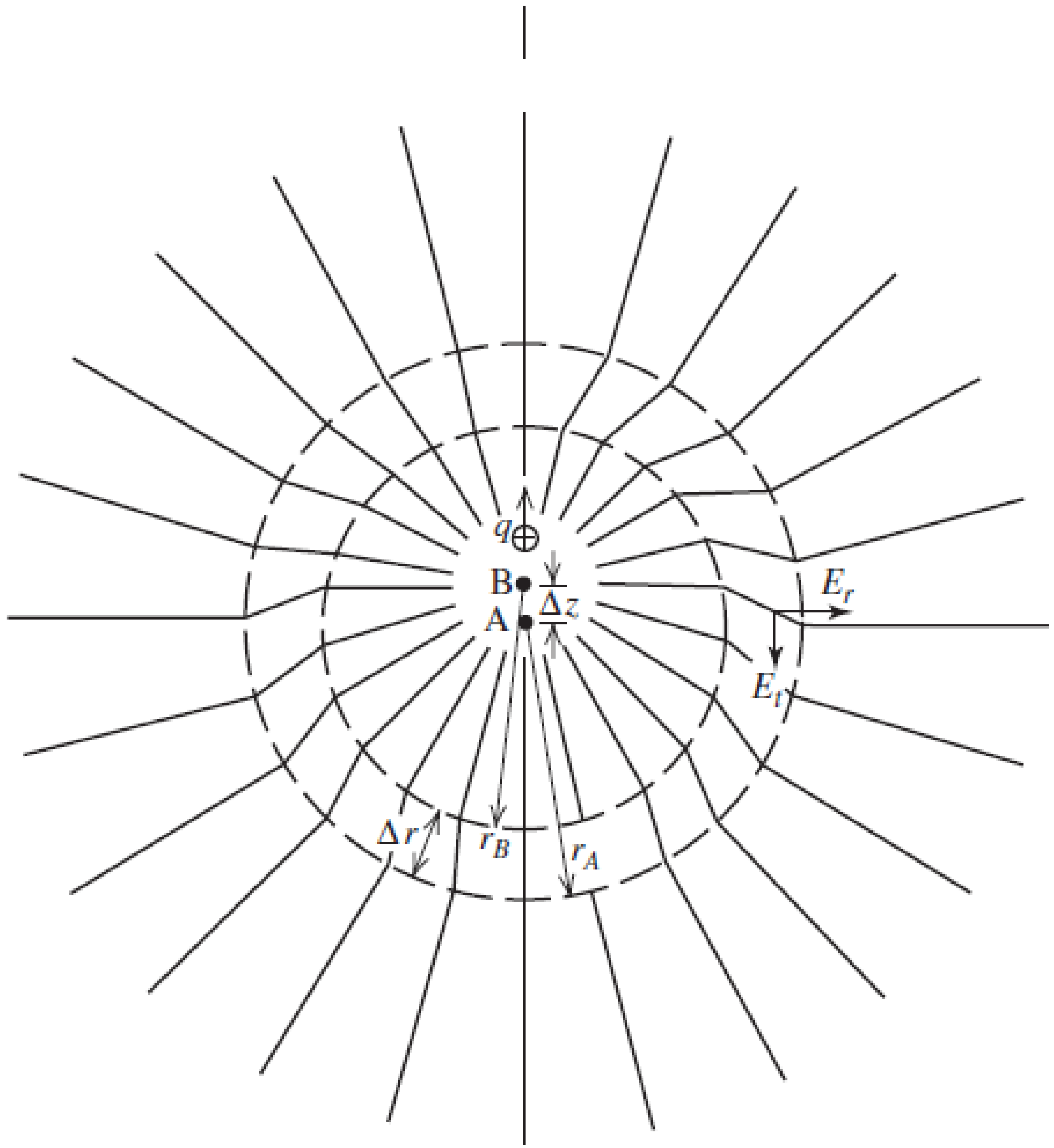


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$$\nabla \times \mathbf{E} = -j\omega\mu\mathbf{H}$$

$$\nabla \times \mathbf{H} = j\omega\varepsilon\mathbf{E} + \mathbf{J}$$

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon}$$

$$\nabla \cdot \mathbf{H} = 0 \quad \Rightarrow \quad \mathbf{H} = \frac{1}{\mu}\nabla \times \mathbf{A} \quad \Rightarrow \quad \nabla \times (\mathbf{E} + j\omega\mathbf{A}) = 0 \quad \Rightarrow \quad \mathbf{E} = -j\omega\mathbf{A} - \nabla\Phi$$

$$\nabla \cdot \mathbf{J} = -j\omega\rho$$

$$\nabla \times \mathbf{H} = \frac{1}{\mu}\nabla \times \nabla \times \mathbf{A} = j\omega\varepsilon\mathbf{E} + \mathbf{J} \qquad \nabla \times \nabla \times \mathbf{A} \equiv \nabla(\nabla \cdot \mathbf{A}) - \nabla^2\mathbf{A}$$

$$\Downarrow$$

$$\nabla(\nabla \cdot \mathbf{A}) - \nabla^2\mathbf{A} = j\omega\mu\varepsilon(-j\omega\mathbf{A} - \nabla\Phi) + \mu\mathbf{J}$$

$$\nabla^2\mathbf{A} + \omega^2\mu\varepsilon\mathbf{A} - \nabla(j\omega\mu\varepsilon\Phi + \nabla \cdot \mathbf{A}) = -\mu\mathbf{J} \qquad \nabla \cdot \mathbf{A} = -j\omega\mu\varepsilon\Phi$$

$$\boxed{\nabla^2\mathbf{A} + \omega^2\mu\varepsilon\mathbf{A} = -\mu\mathbf{J}} \qquad \boxed{\mathbf{A} = \iiint_{\upsilon'} \mu\mathbf{J}\frac{e^{-j\beta R}}{4\pi R}\,d\upsilon'}$$

$$\mathbf{A} = \iiint_{v'} \mu \mathbf{J} \frac{e^{-j\beta R}}{4\pi R} dv' \quad \Rightarrow \quad \mathbf{H} = \frac{1}{\mu} \nabla \times \mathbf{A} \quad \Rightarrow \quad \mathbf{E} = \frac{1}{j\omega\varepsilon} \nabla \times \mathbf{H}$$

$$\mathbf{H} = \frac{I\,\Delta z}{4\pi} j\beta \left(1 + \frac{1}{j\beta r}\right) \frac{e^{-j\beta r}}{r} \sin\theta\,\hat{\boldsymbol{\phi}}$$

$$\mathbf{E} = \frac{I\,\Delta z}{4\pi} j\omega\mu \left[1 + \frac{1}{j\beta r} - \frac{1}{(\beta r)^2}\right] \frac{e^{-j\beta r}}{r} \sin\theta\,\hat{\boldsymbol{\theta}}$$

$$+ \frac{I\,\Delta z}{2\pi} \eta \left[\frac{1}{r} - j\frac{1}{\beta r^2}\right] \frac{e^{-j\beta r}}{r} \cos\theta\,\hat{\mathbf{r}}$$

$$\boxed{\begin{aligned} \mathbf{E} &= \frac{I\Delta z}{4\pi} j\omega\mu \frac{e^{-j\beta r}}{r} \sin\theta\,\hat{\boldsymbol{\theta}} \\ \mathbf{H} &= \frac{I\Delta z}{4\pi} j\beta \frac{e^{-j\beta r}}{r} \sin\theta\,\hat{\boldsymbol{\phi}} \end{aligned}}$$

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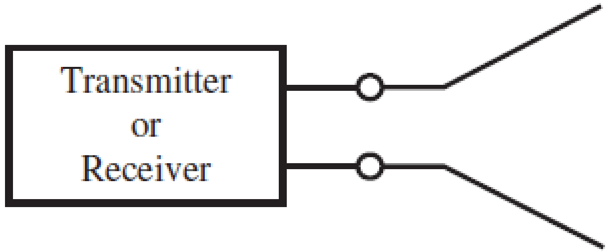
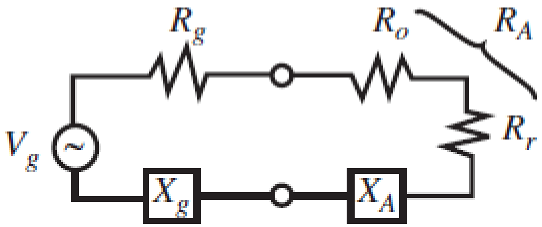



($a$) General antenna model.

$$\boxed{Z_A = R_A + jX_A}$$ *input impedance*




($b$) Equivalent model for a transmitting antenna.

$$e_r = \frac{P}{P_{in}} = \frac{P}{P + P_o}$$

$$e_r = \frac{\frac{1}{2}R_r|I_A|^2}{\frac{1}{2}R_r|I_A|^2 + \frac{1}{2}R_o|I_A|^2} = \frac{R_r}{R_r + R_o} = \frac{R_r}{R_A}$$

## Ejercicio 1.

Para un dipolo infinitamente delgado determine: la distribución de corriente, resistencia de radiación y reactancia de entrada. Considere las siguientes longitudes relativas: $L = \lambda/100$, $L = \lambda/10$, $L = \lambda/4$, $L = \lambda/2$ y $L = \lambda$ (utilice la rutina Matlab DIPOLO.m). Qué conclusiones puede extraer respecto de la variación de esos parmetros con la longitud de onda?

# Dipolo Ideal

- Cuando su longitud L es L<λ/100.
- Se supone que por ser tan corto su corriente es constante.
- Resistencia de radiación

$$R_{rad} = 80\,\pi^2 \left(\frac{L}{\lambda}\right)^2$$

- Altamente capacitivo (línea en ca).
- Eficiencias menores al 10%.

$$R_{loss} = \sqrt{\frac{\mu\omega}{2\sigma}}\,\frac{L}{\pi d}$$

- Patrón

$$F(\theta) = \sin\theta$$

- D=1.5

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```
DIPOLE:
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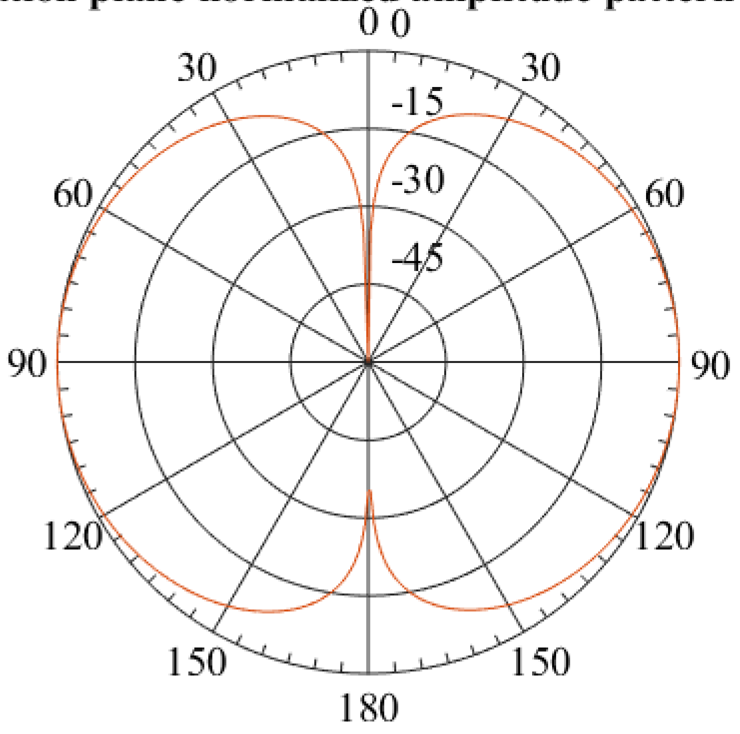
Input parameters:
-----------------
Length of dipole in wavelengths = 0.0100
Radius of dipole in wavelengths = 0.0001000

Output parameters:
------------------
Directivity (dimensionless) = 1.5000
Directivity (dB)     = 1.7611

Radiation resistance based on current maximum (Ohms) =     0.0000
Reactance based on current maximum (Ohms) =   -10.9629

Input resistance (Ohms) =     0.0197
Input reactance (Ohms) = -11111.3752
```

**Elevation plane normalized amplitude pattern (dB)**



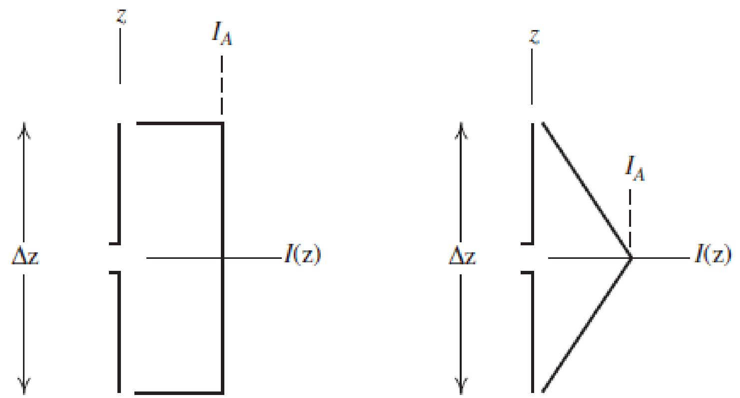
# Dipolo Corto

- Cuando su longitud L es L<λ/10.
- Se supone que la corriente tiene distribución triangular.
- Resistencia de radiación:
- Capacitivo (línea en ca).
- Eficiencia de 50 a 90 %.
- Patrón
- D=1.5

$$R_{rad} = 20\,\pi^2 \left(\frac{L}{\lambda}\right)^2$$

$$R_{loss} = \sqrt{\frac{\mu\omega}{2\sigma}}\,\frac{L}{3\pi d}$$

$$F(\theta) = \sin\theta$$

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```
DIPOLE:
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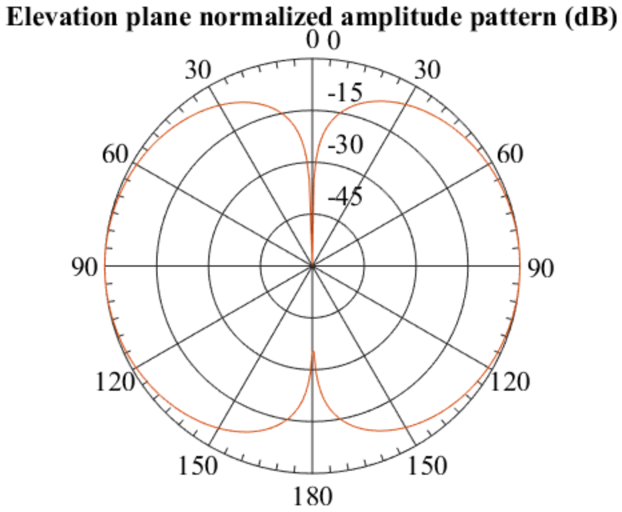
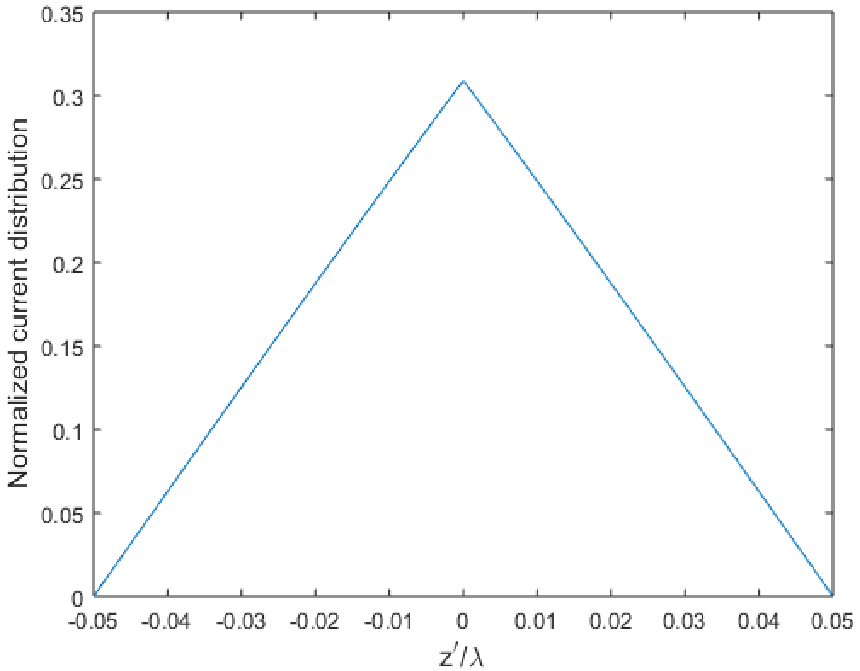
Input parameters:
-----------------
Length of dipole in wavelengths = 0.1000
Radius of dipole in wavelengths = 0.0010000

Output parameters:
------------------
Directivity (dimensionless) = 1.5050
Directivity (dB)     = 1.7752

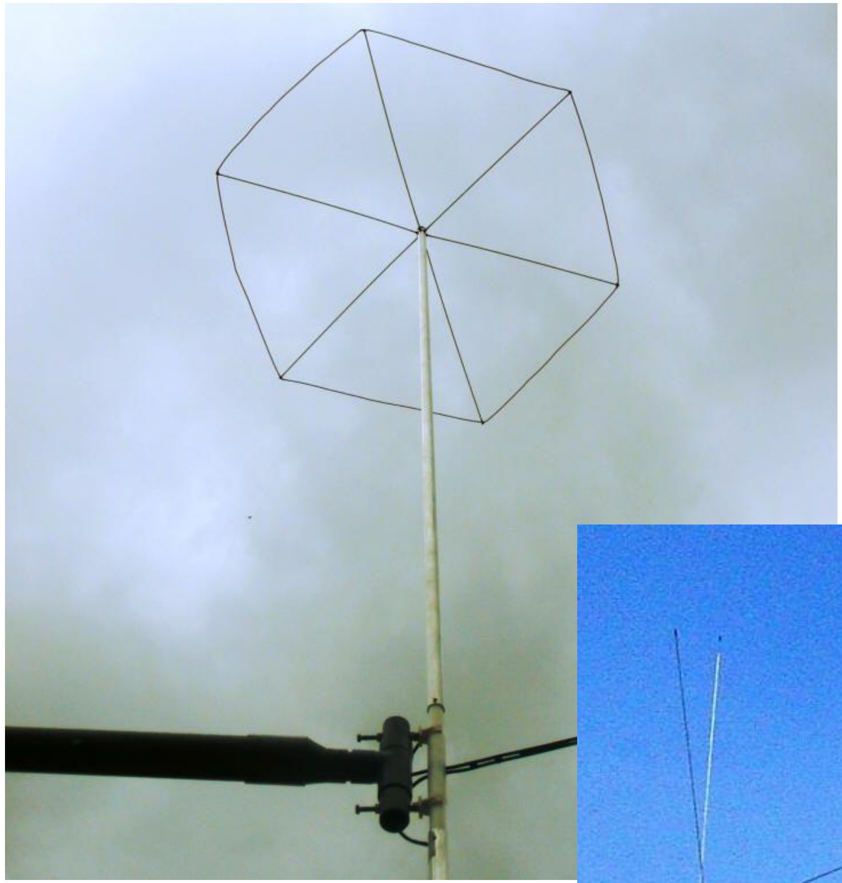
Radiation resistance based on current maximum (Ohms) =      0.1910
Reactance based on current maximum (Ohms) =  -102.2146

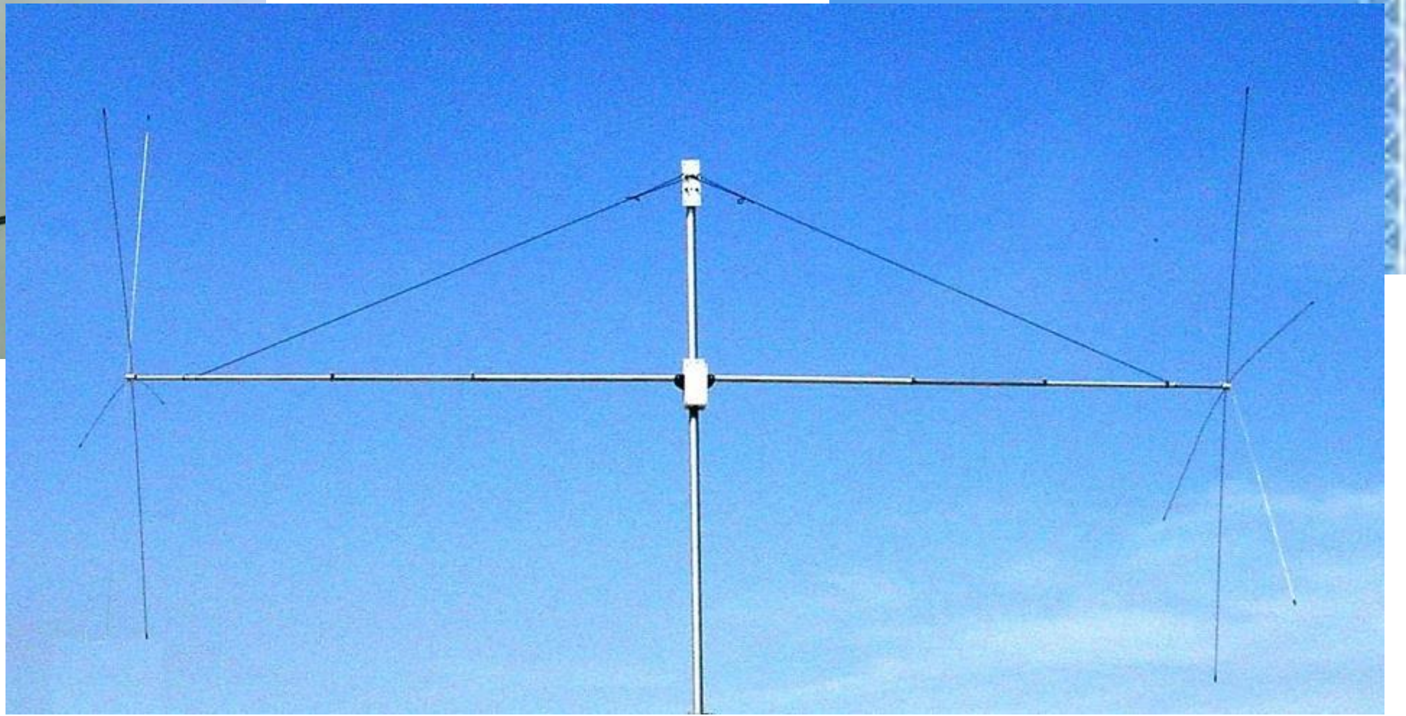
Input resistance (Ohms) =      2.0002
Input reactance (Ohms) = -1070.4051
```



# Dipolo Corto (cargado)



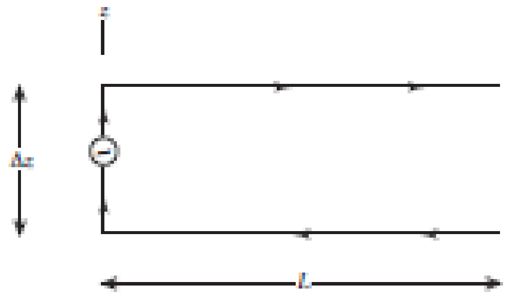


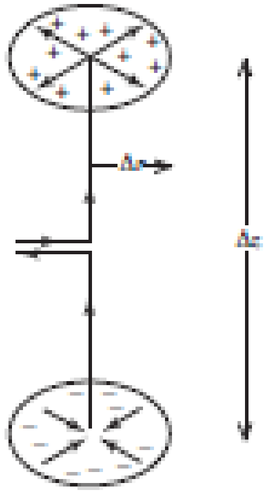
# Dipolo Corto (cargado)

- Se agregan cargas en sus extremos (por ejemplo dos platos o varillas) para acumular carga.
- Distribución de corriente constante.
- Más eficiente.

$$R_{rad} = 80\,\pi^2 \left(\frac{L}{\lambda}\right)^2 \qquad R_{loss} = \sqrt{\frac{\mu\omega}{2\sigma}}\,\frac{L}{\pi d}$$

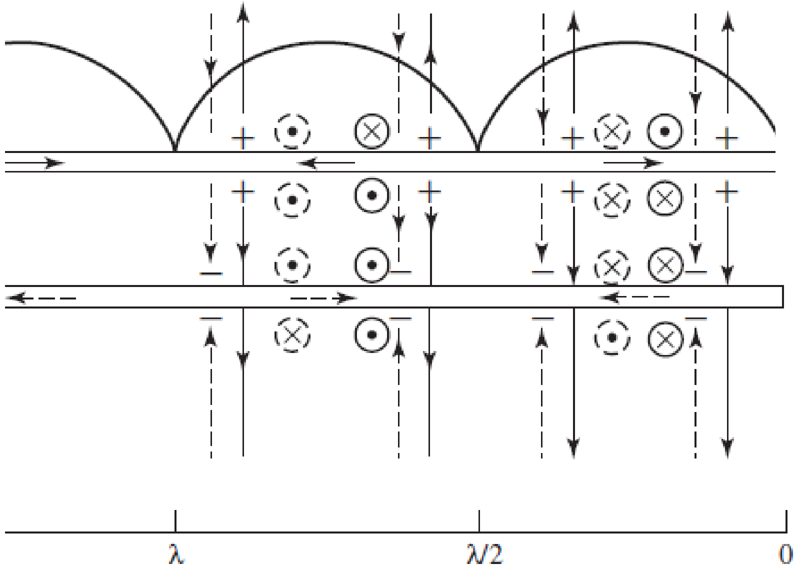
- Patrón $F(\theta) = \sin\theta$

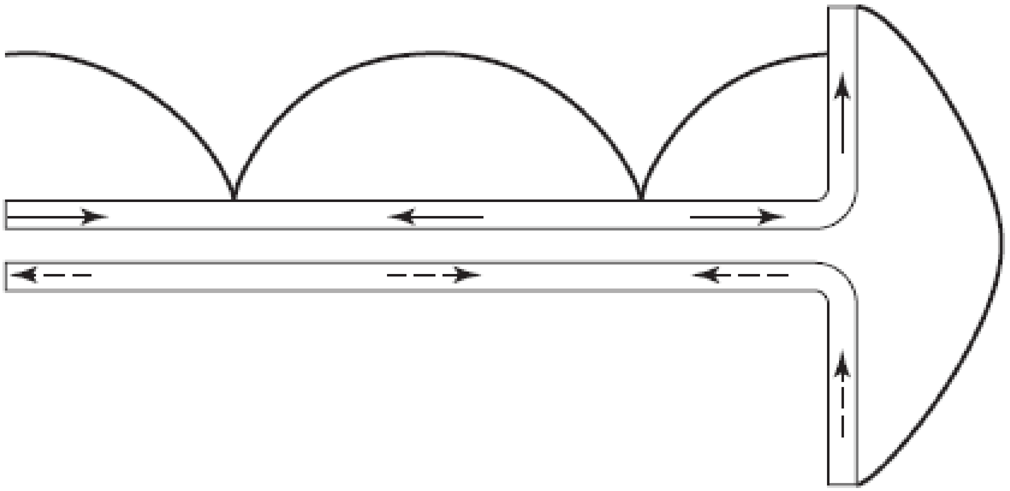




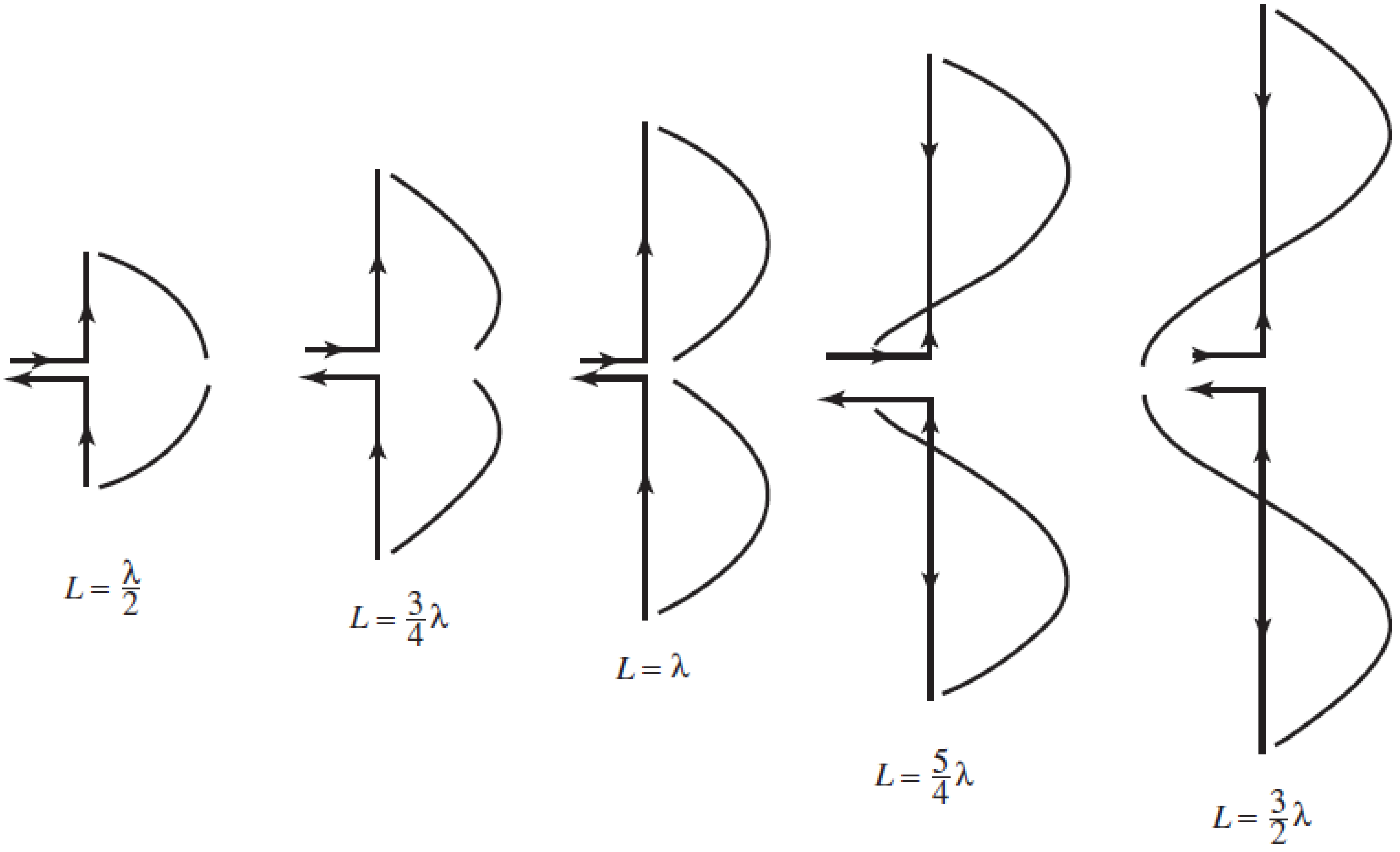
# Dipolo λ/2 (y más)

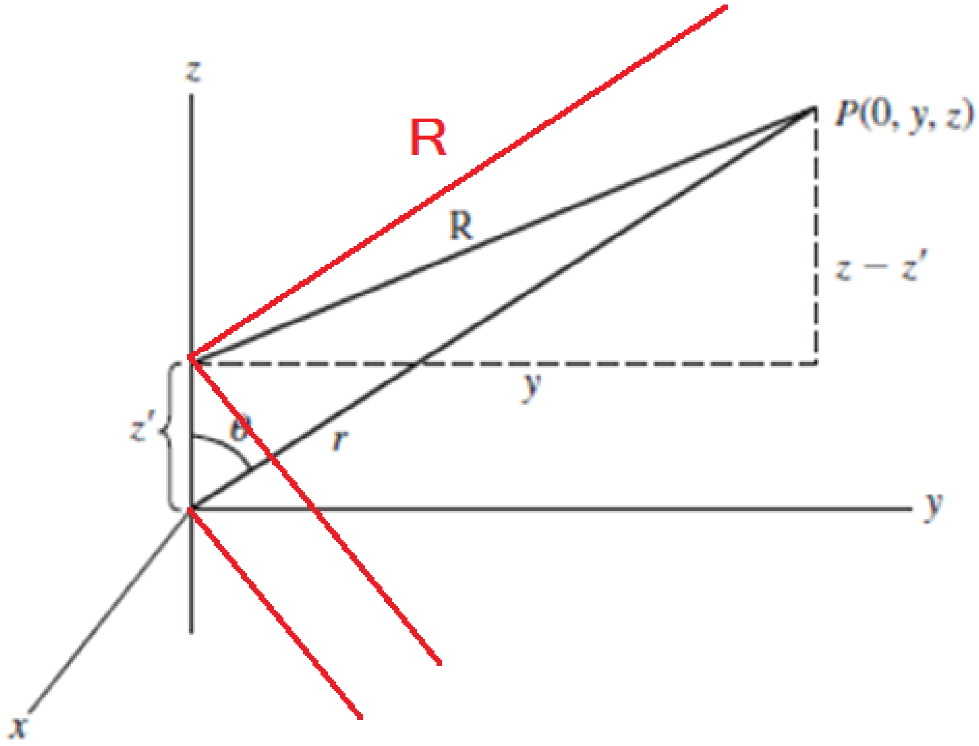
- Se supone que la distribución de corrientes es sinusoidal.
- El patrón de radiación depende de la longitud L.



$$\boxed{I(z) = I_m \sin\left[\beta\left(\frac{L}{2} - |z|\right)\right], \quad |z| < \frac{L}{2}}$$


$L = \frac{\lambda}{2}$
$L = \frac{3}{4}\lambda$
$L = \lambda$
$L = \frac{5}{4}\lambda$
$L = \frac{3}{2}\lambda$




$$A_z = \mu \int I(z') \frac{e^{-j\beta R}}{4\pi R} dz'$$

$$R = \sqrt{y^2 + (z - z')^2}$$

En el denominador del integrando $R \approx r$

En el exponente del integrando $R \approx r - z' \cos\theta$

$$R \approx r - z' \cos\theta$$

$$A_z = \mu \int I(z') \frac{e^{-j\beta(r - z'\cos\theta)}}{4\pi r} dz' = \mu \frac{e^{-j\beta r}}{4\pi r} \boxed{\int I(z') e^{j\beta z' \cos\theta} dz'}$$

$$R \approx r$$

$$\mathbf{H} = \hat{\boldsymbol{\phi}} \frac{j\beta}{\mu} \sin\theta \, \mu \frac{e^{-j\beta r}}{4\pi r} \int I(z') e^{j\beta z' \cos\theta} dz'$$

$$\mathbf{E} = -j\omega A_\theta \hat{\boldsymbol{\theta}} = j\omega \sin\theta \, A_z \hat{\boldsymbol{\theta}}$$

$$\boxed{\frac{\cos[(\beta L/2) \ \cos\theta] - \cos(\beta L/2)}{\sin\theta}}$$

**El patrón depende de la longitud de la antena**

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- Si L= λ/2 entonces βL/2=π/2 D=1.64

$$F(\theta)=\frac{\cos[(\pi/2)\ \cos\theta]}{\sin\theta}\quad (L=\lambda/2)$$

- Si L= λ entonces βL/2=π D=???

$$F(\theta)=\frac{\cos(\pi\cos\theta)+1}{2\sin\theta}\quad (L=\lambda)$$

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```
DIPOLE:
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Input parameters:
-----------------
Length of dipole in wavelengths = 1.0000
Radius of dipole in wavelengths = 0.0100000

Output parameters:
------------------
Directivity (dimensionless) = 2.4110
Directivity (dB)     = 3.8220

Radiation resistance based on current maximum (Ohms) =    199.0877
Reactance based on current maximum (Ohms) =    125.7912
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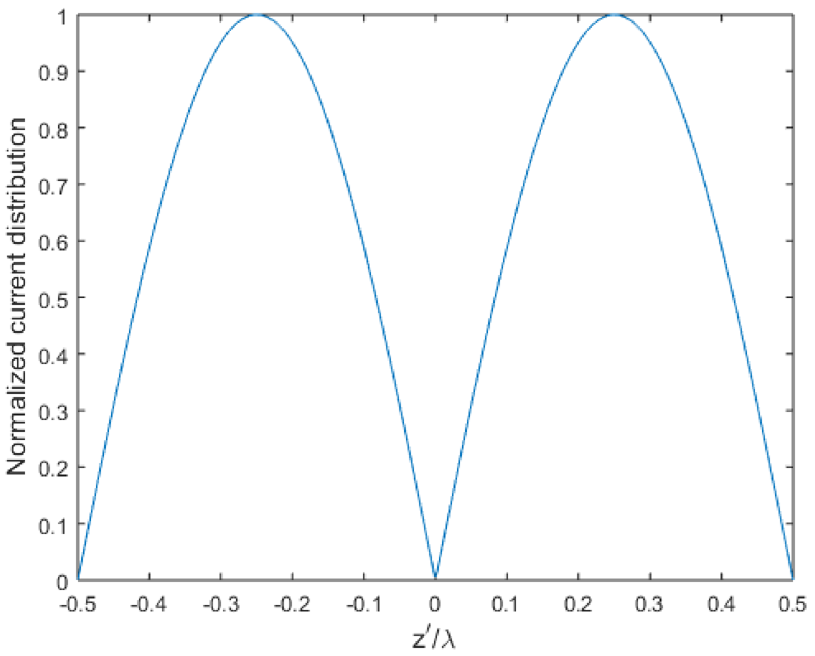
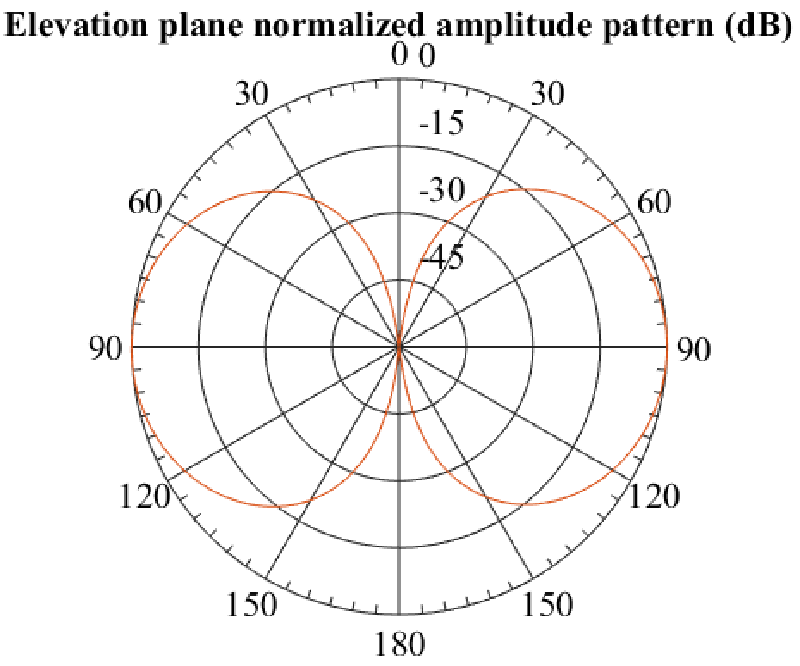
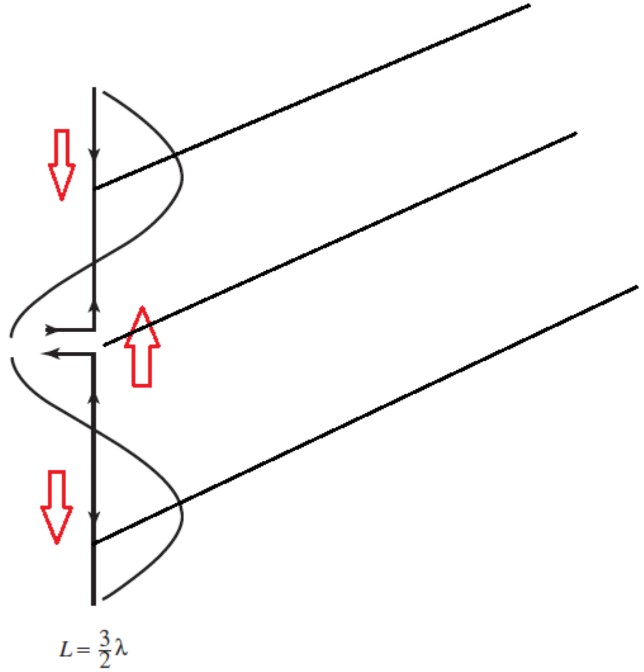
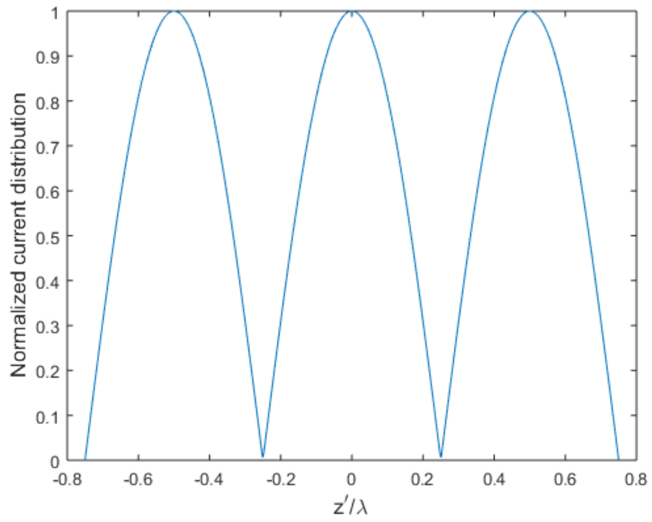


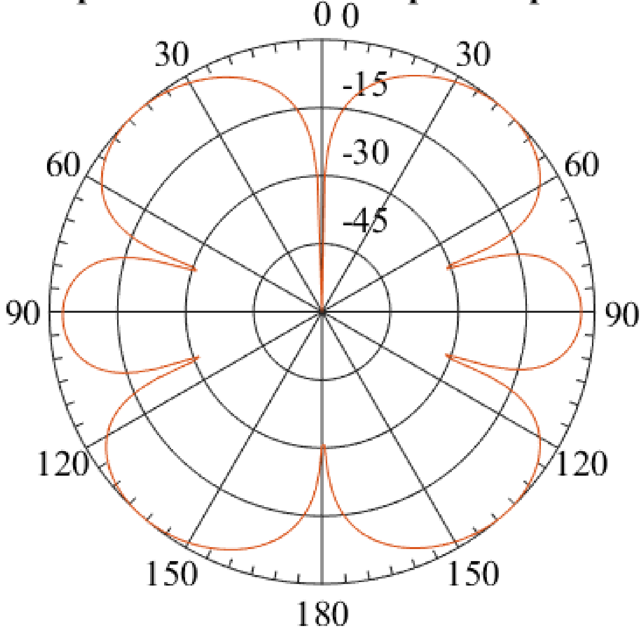






$$F(\theta) = 0.7148\,\frac{\cos\left(\frac{3}{2}\pi\ \cos\theta\right)}{\sin\theta}\quad\left(L = \frac{3}{2}\,\lambda\right)$$

**Elevation plane normalized amplitude pattern (dB)**




Puedo considerar la antena como 3 dipolos separados con corrientes en sentidos opuestos. En el plano horizontal (θ=90°) el campo del dipolo central se resta a de los dipolos de los extremos. La directividad es 2.2 y la dirección de máxima radiación en aprox. 45°.

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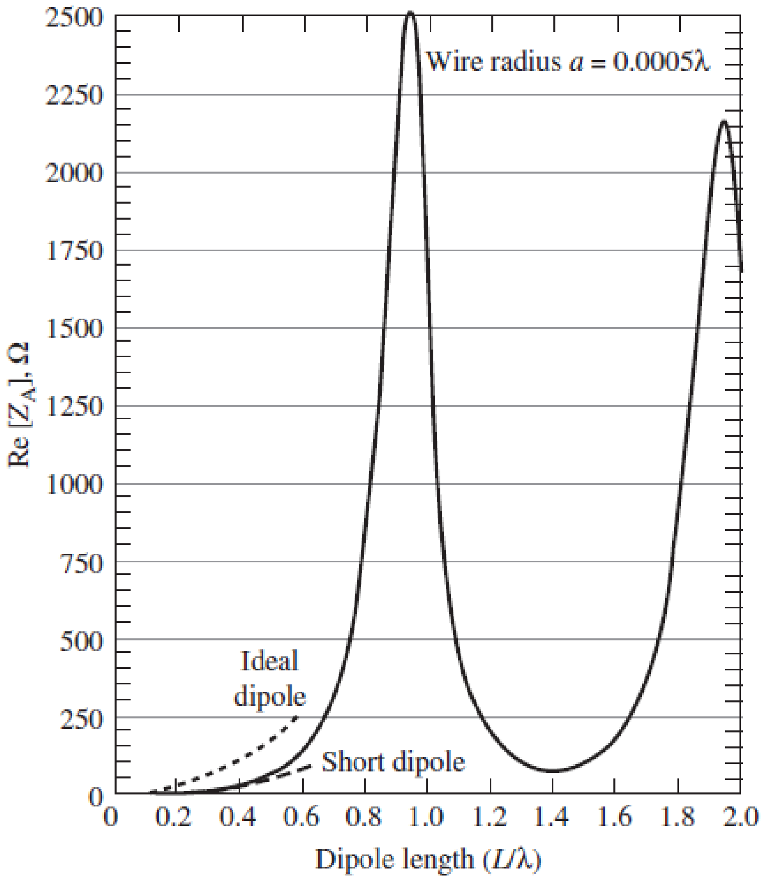
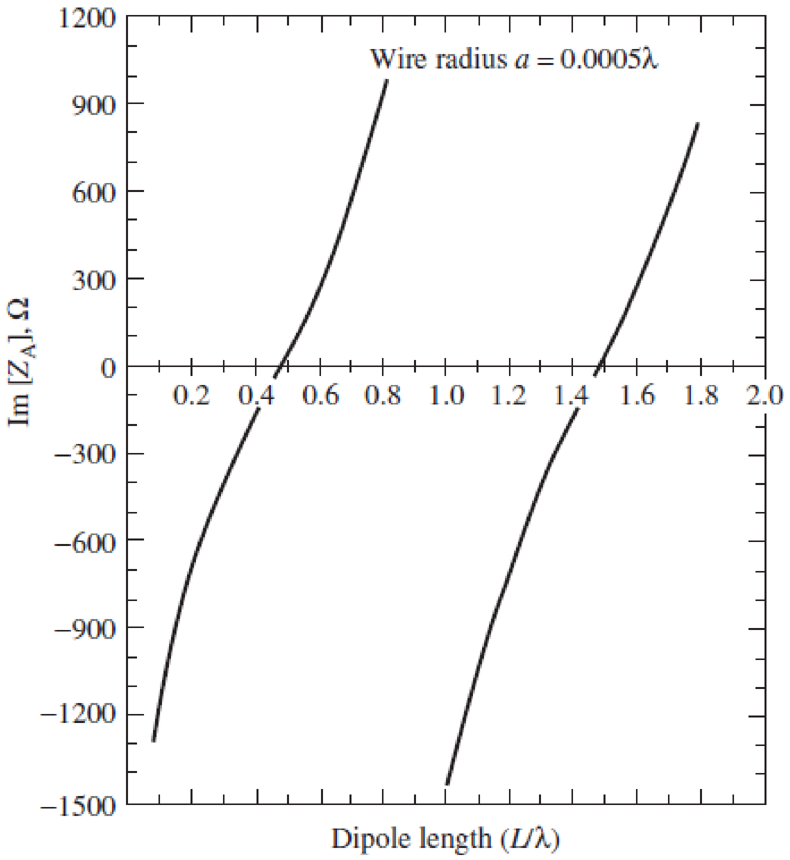
# Dipolo λ/2 (y más)




$$Z_A = 73 + j42.5\,\Omega \quad \left(L = \frac{\lambda}{2}\right)$$

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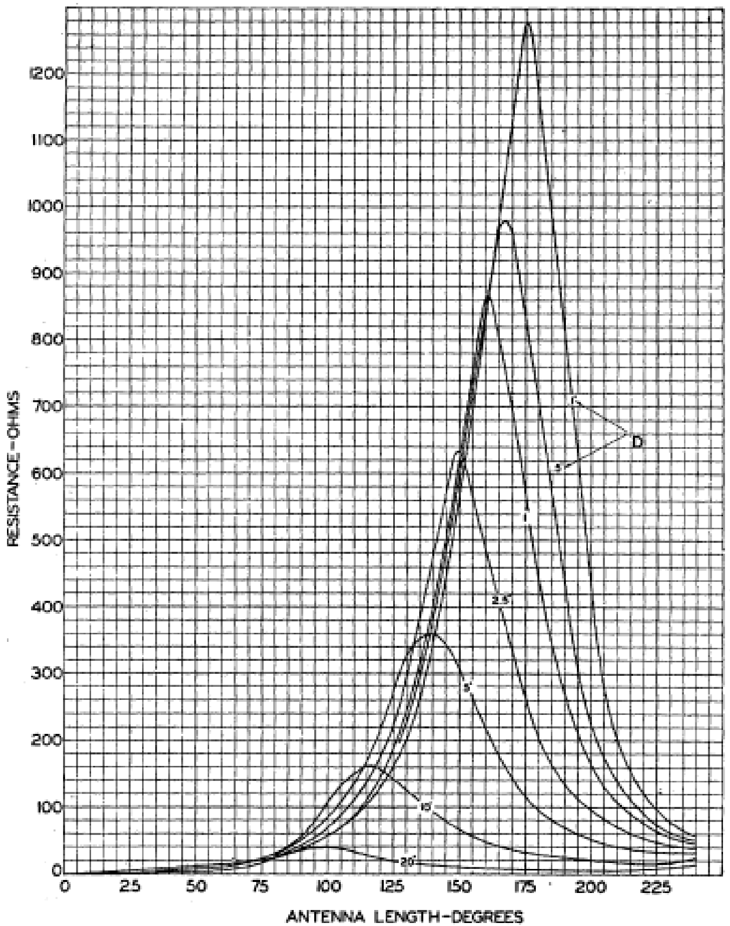
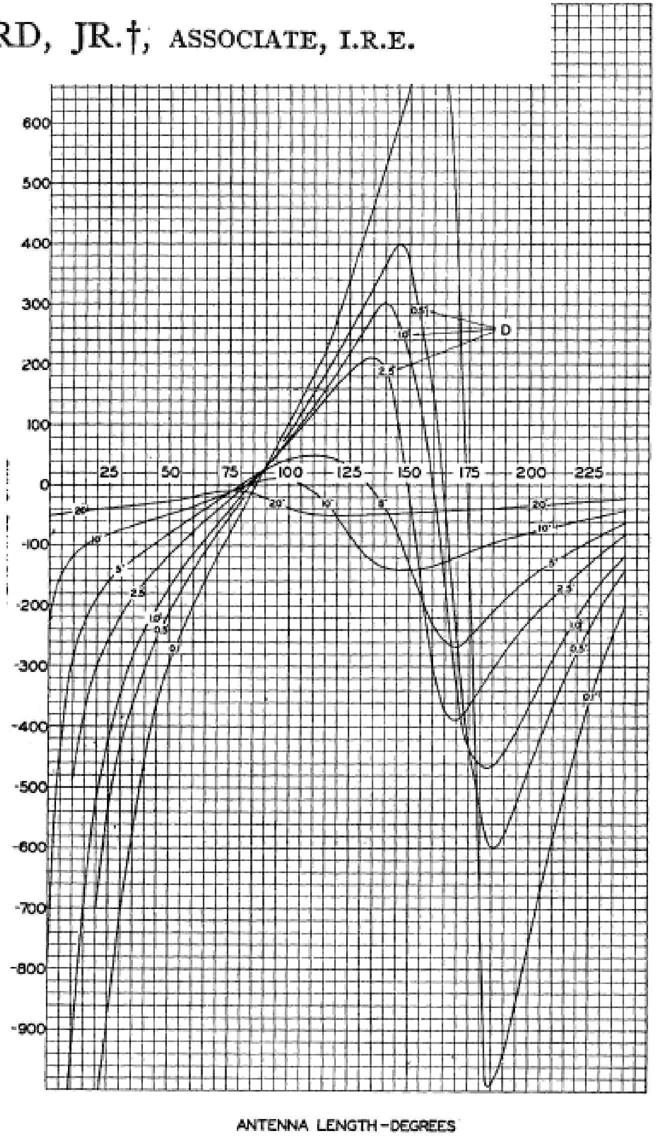
# Dipolo λ/2 ( Brown Woodward)

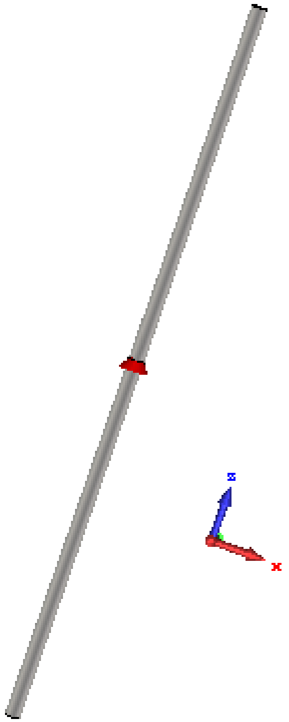
## Experimentally Determined Impedance Characteristics of Cylindrical Antennas*

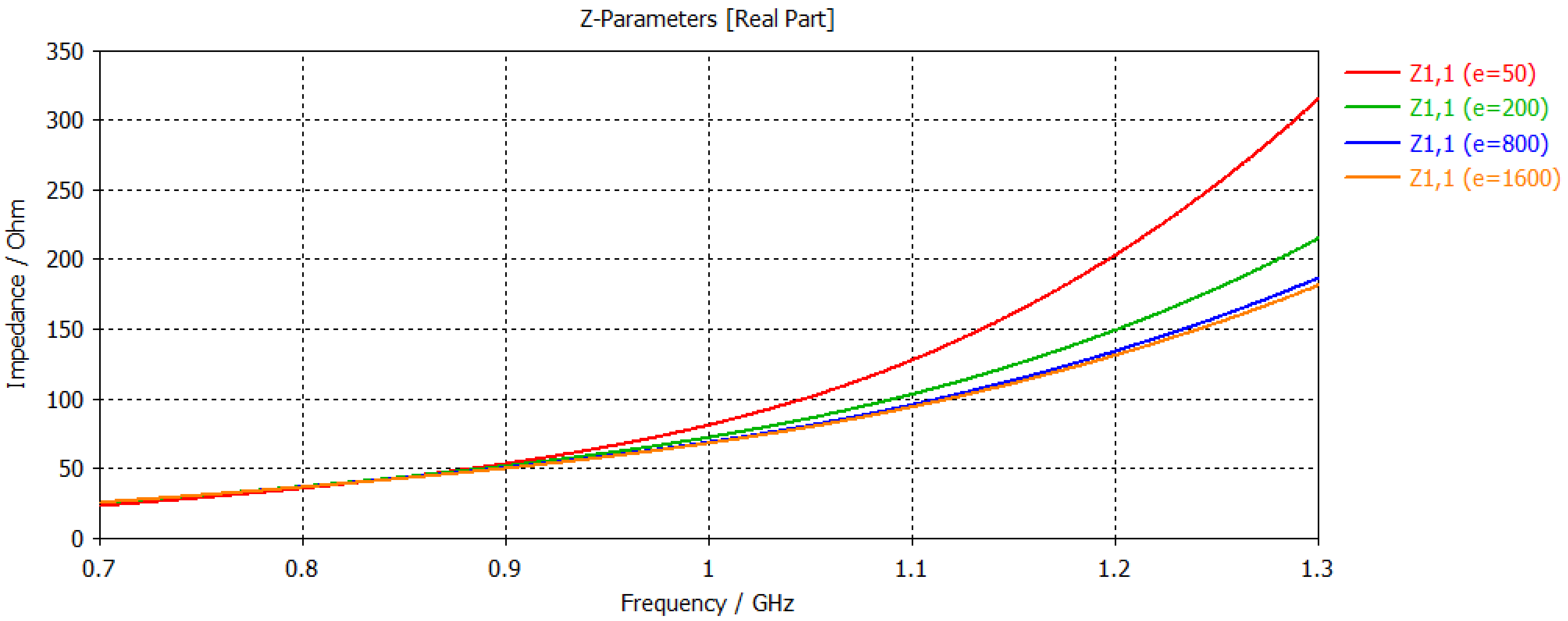
GEORGE H. BROWN†, FELLOW, I.R.E., AND O. M. WOODWARD, JR.†, ASSOCIATE, I.R.E.



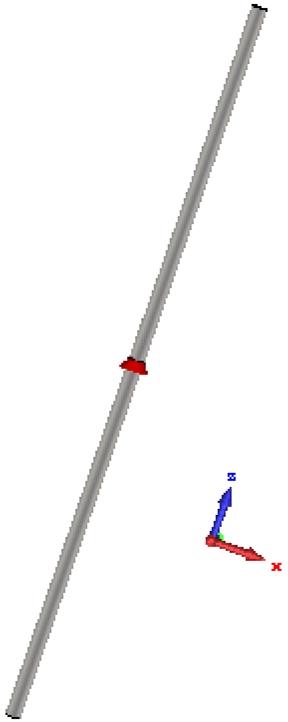
# Dipolo cilíndrico

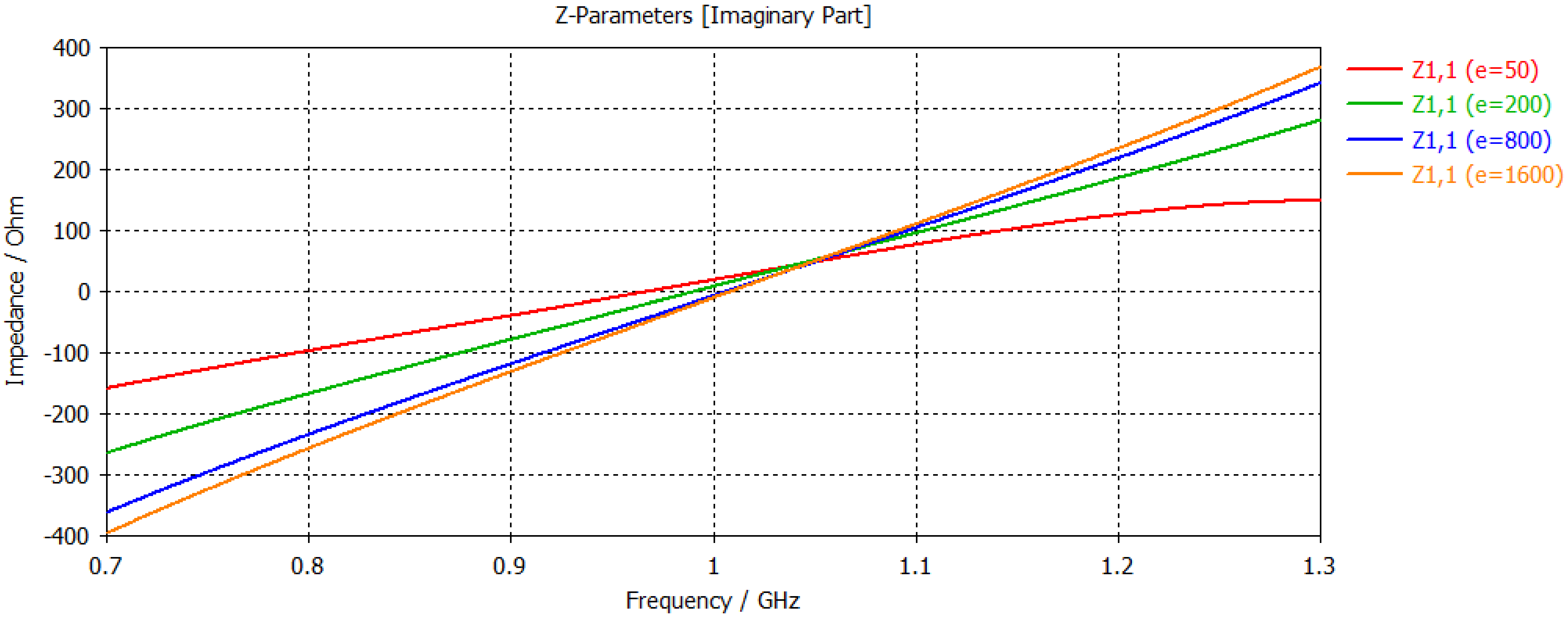





La resistencia del dipolo aumenta a medida que aumenta su grosor

# Dipolo cilíndrico






La reactancia del dipolo tiene cambios más leves con la frecuencia a medida que se hace más grueso.

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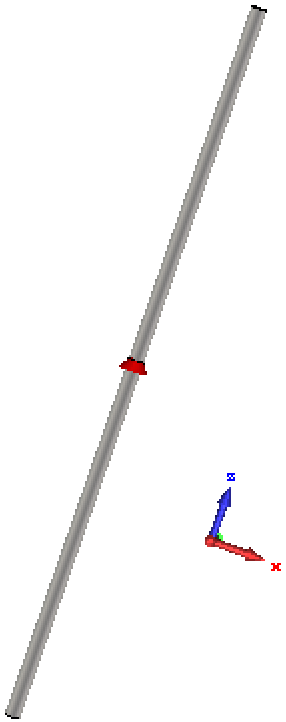
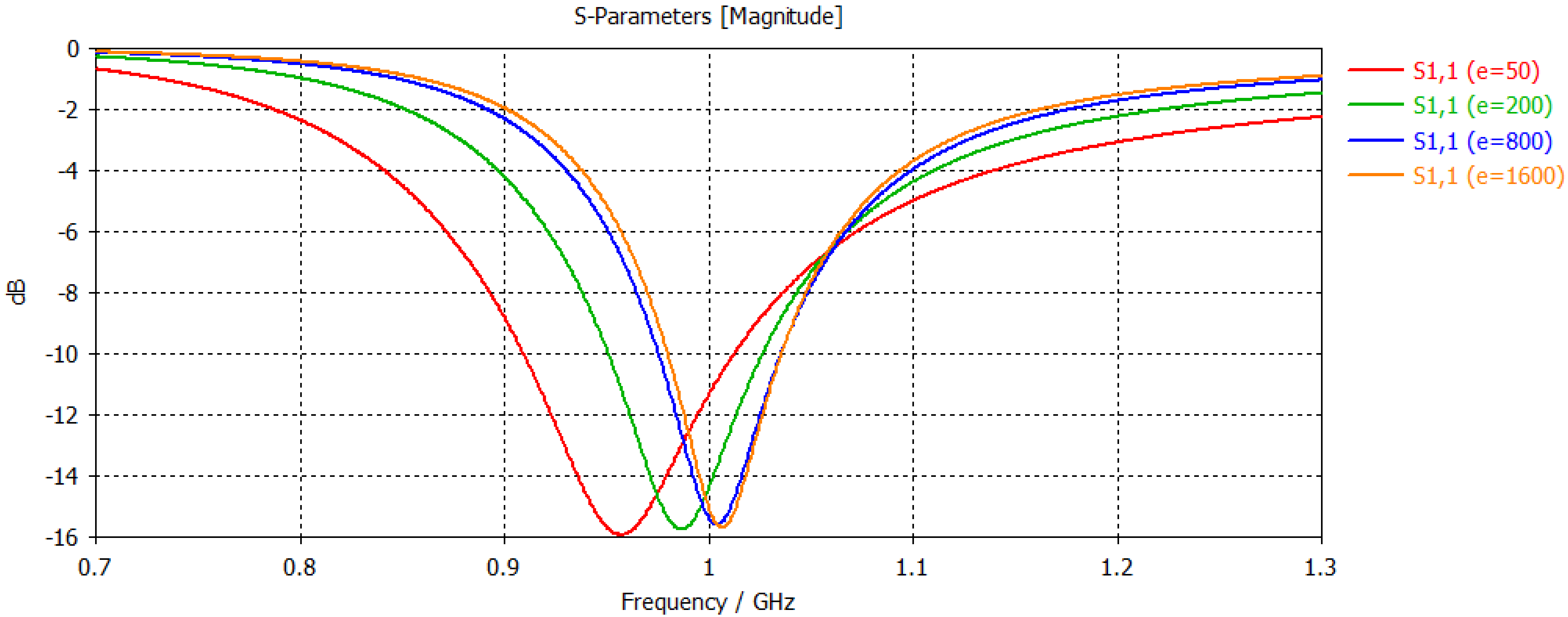
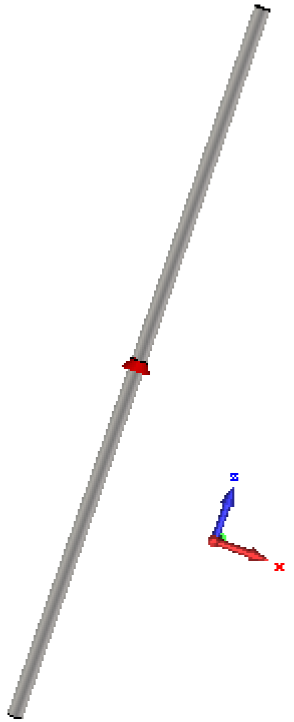
# Dipolo cilíndrico

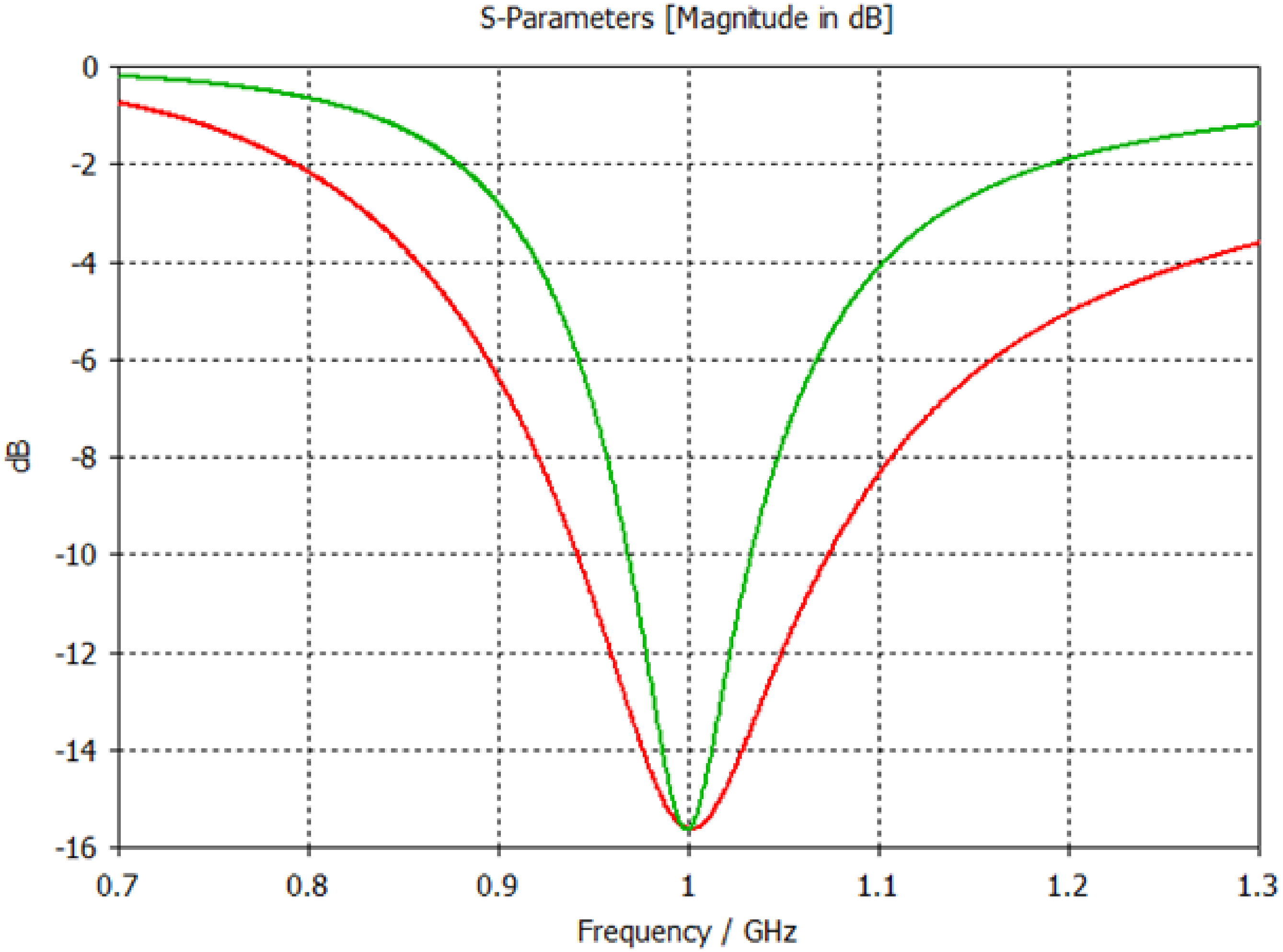



A medida que el dipolo se hace más grueso su frecuencia de resonancia es menor y su ancho de banda es mayo

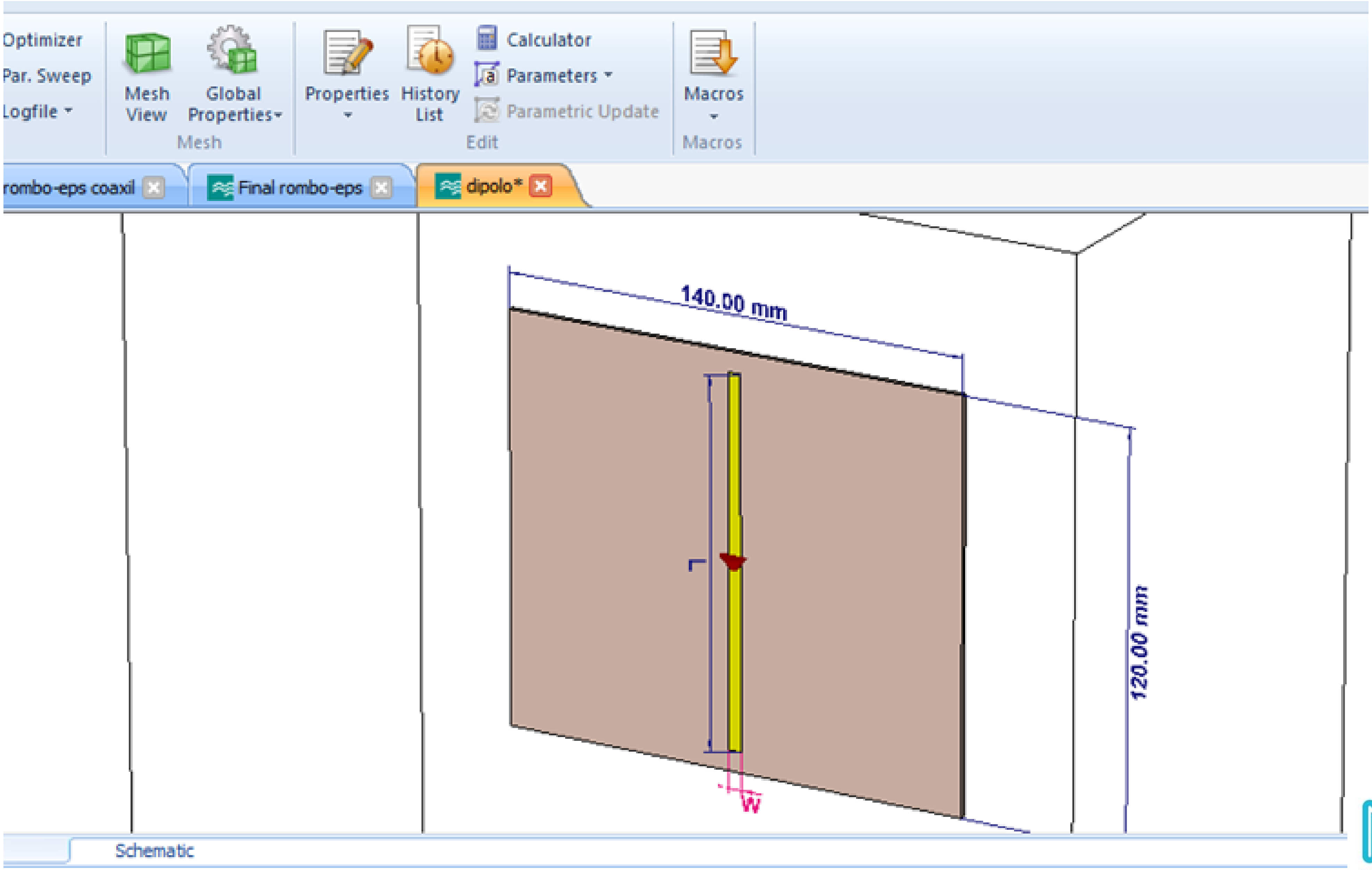
# Dipolo cilíndrico



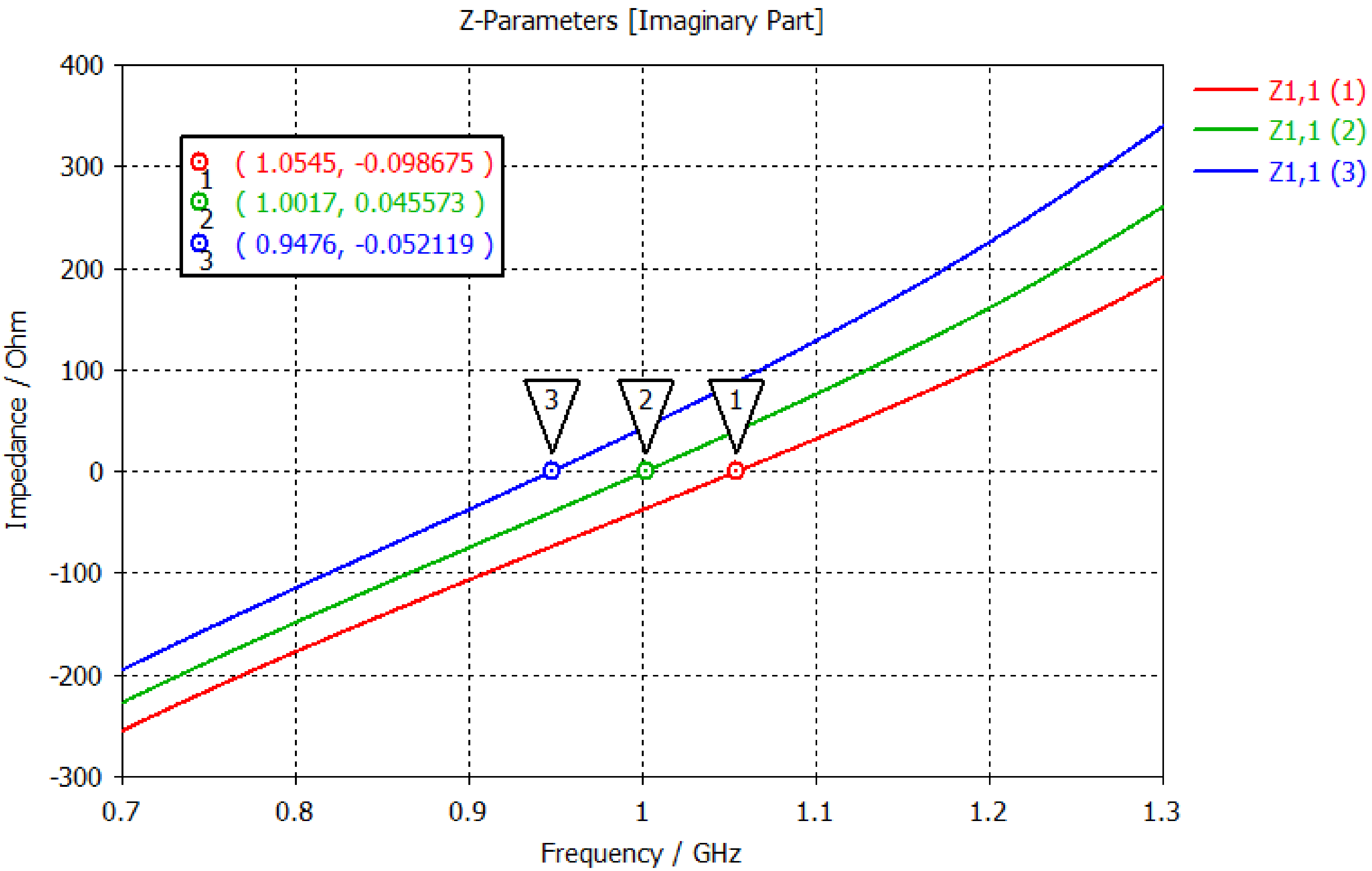




La longitud del dipolo para que resuene a 1 GHz deberá ser menor a λ/2 (150 mm), y cuanto menor dependerá de su grosor. La curva en color verde corresponde a un dipolo de 142 mm de longitud y 0.6 mm de diámetro. La curva en color rojo corresponde a un dipolo de 137 mm de largo y 5.3 mm de diámetro.

# Dipolos en PCB

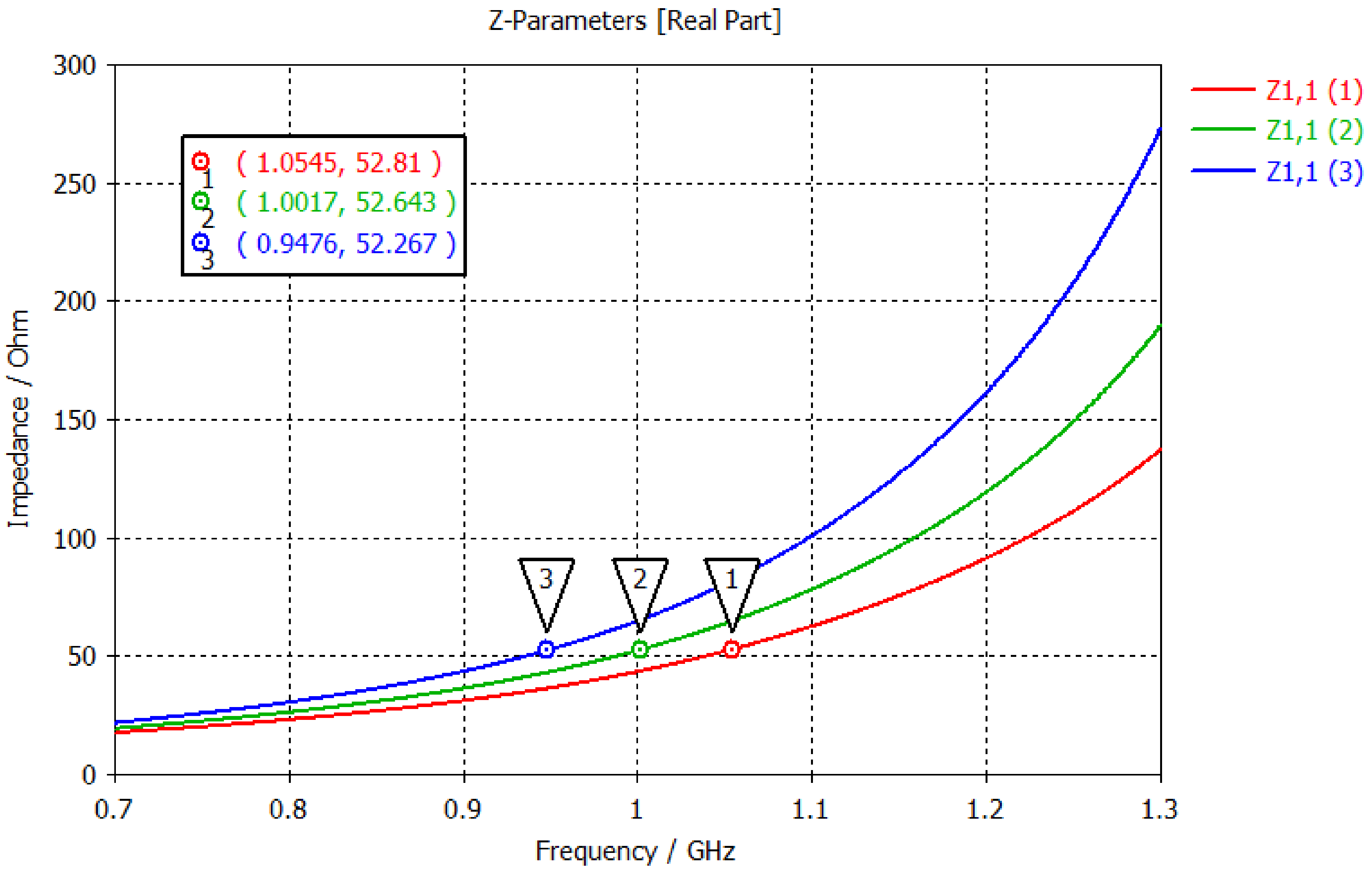


# Dipolos  en PCB (distintas L)



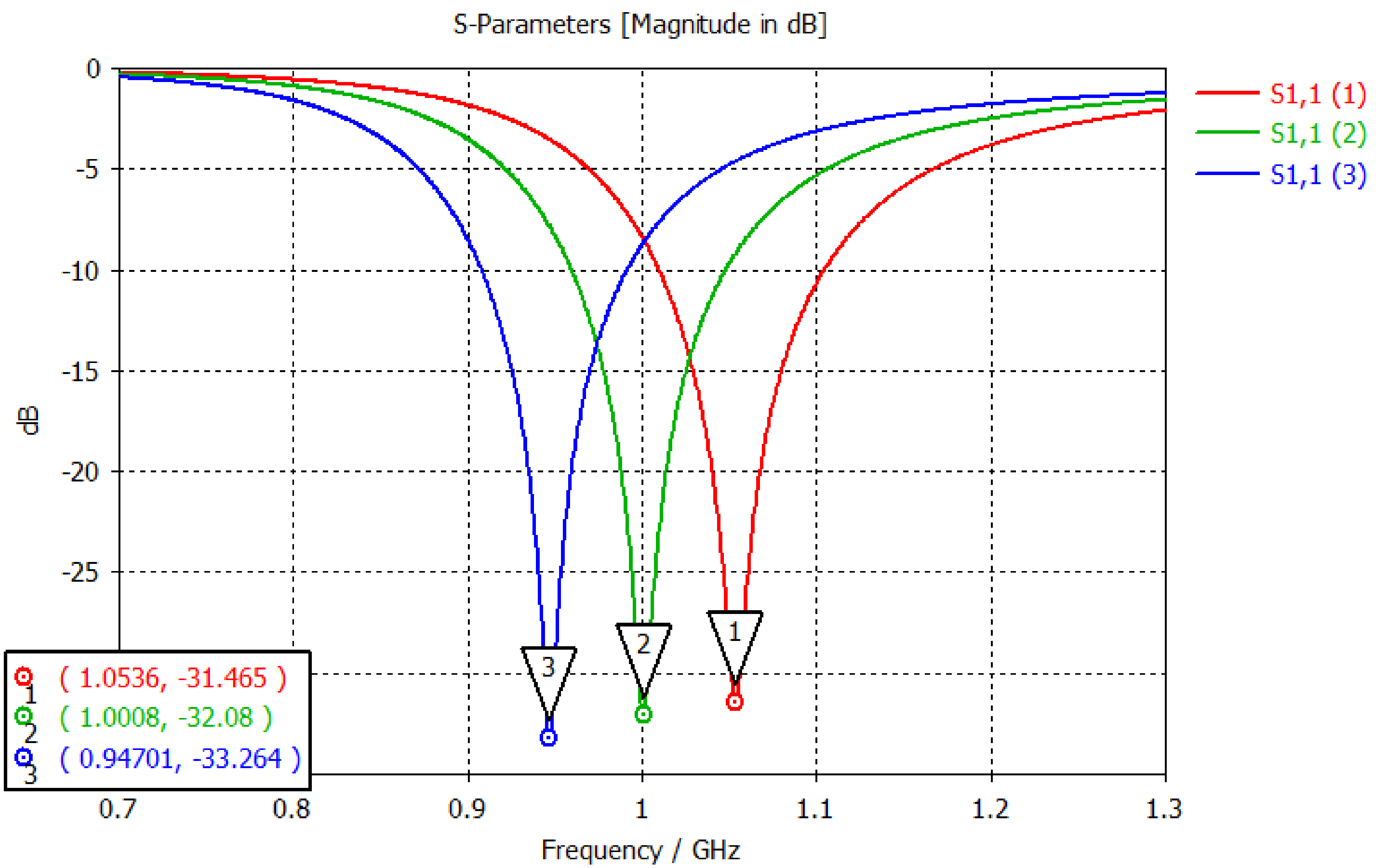

Reactancia de entrada del dipolo para ancho  de la pista  W=0.5 mm y longitudes 51.5mm, 54.5 mm y 57.5 mm.

# Dipolos  en PCB (distintas L)



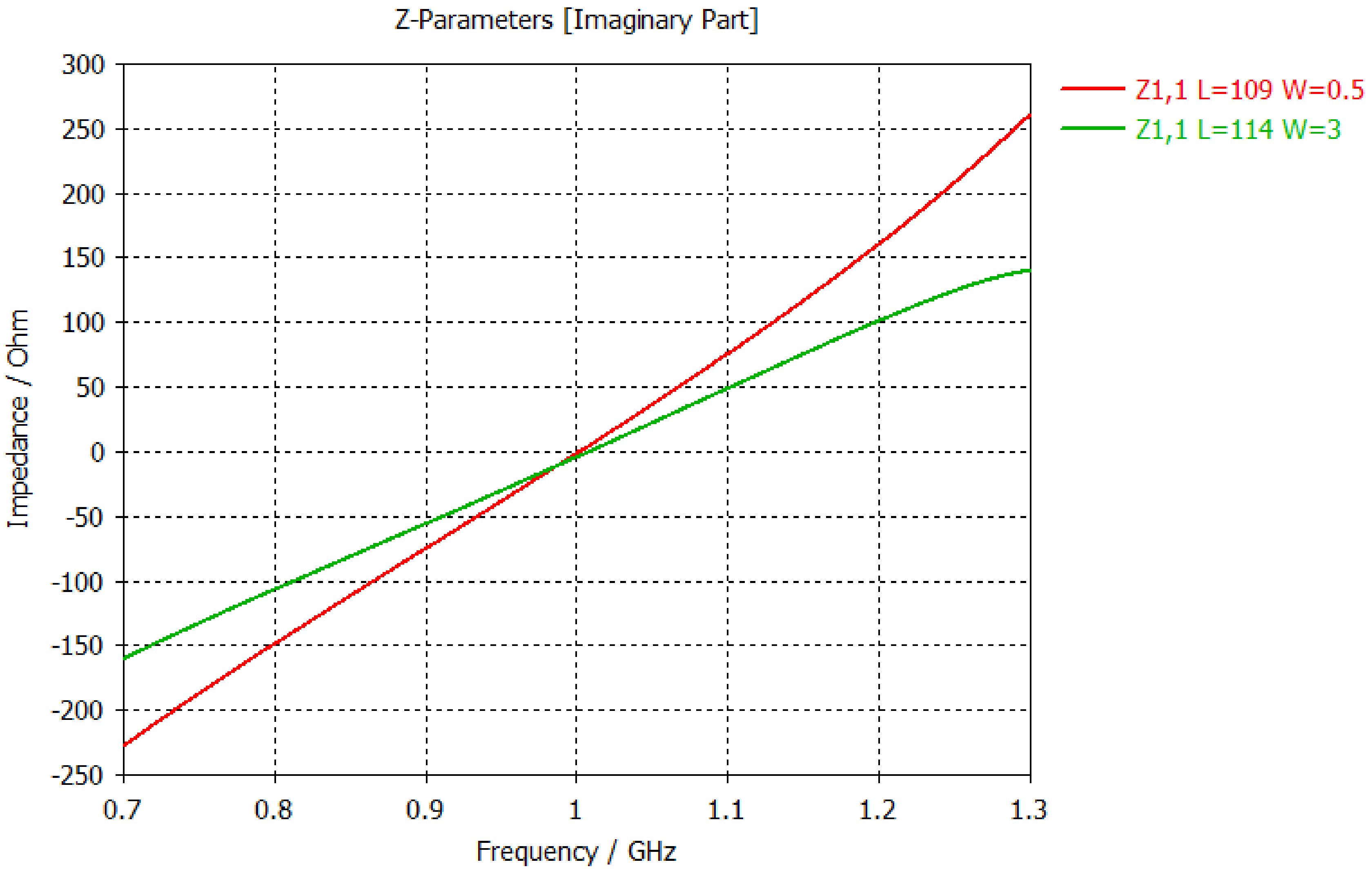

Resistencia de entrada del dipolo para ancho  de la pista  W=0.5 mm y longitudes 51.5mm, 54.5 mm y 57.5 mm.

# Dipolos en PCB (distintas L)



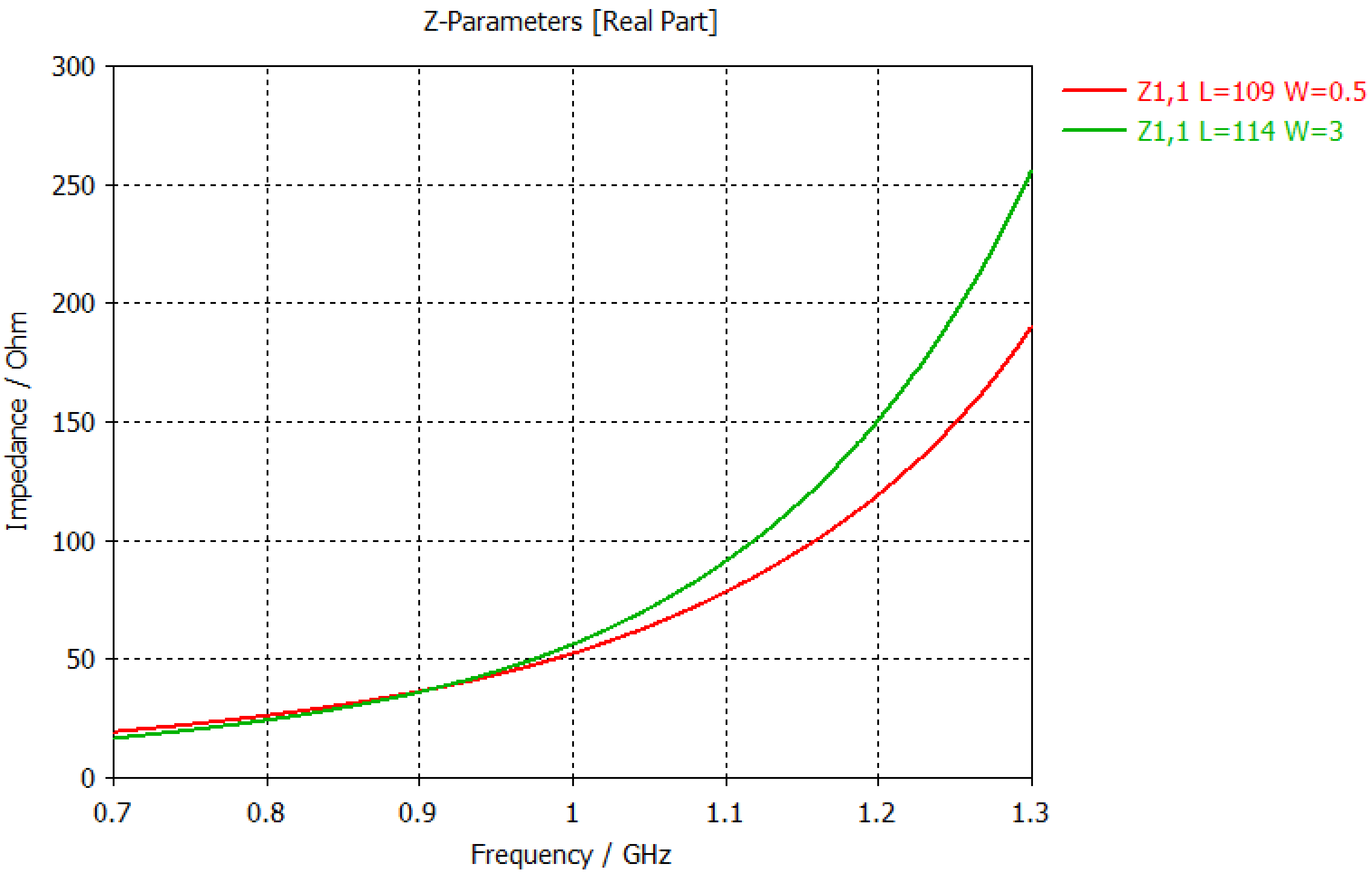

Coeficiente de reflexión S11 del dipolo para ancho de la pista W=0.5 mm y longitudes 51.5mm, 54.5 mm y 57.5 mm.

# Dipolos en PCB

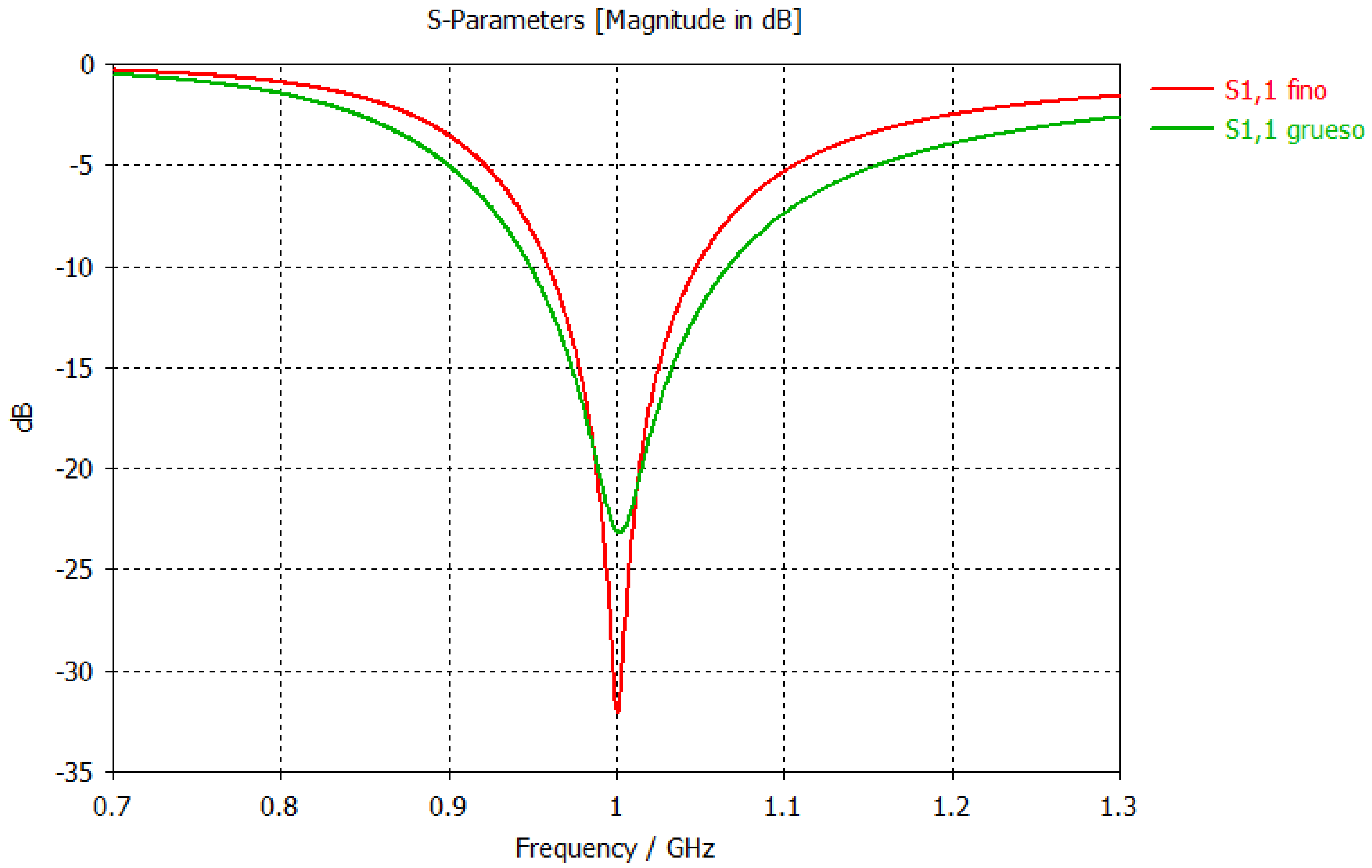



Resistencia de entrada para el dipolo “grueso” de ancho 3mm y largo 114mm, y para el dipolo “delgado” de ancho 0.5mm y largo 109 mm.

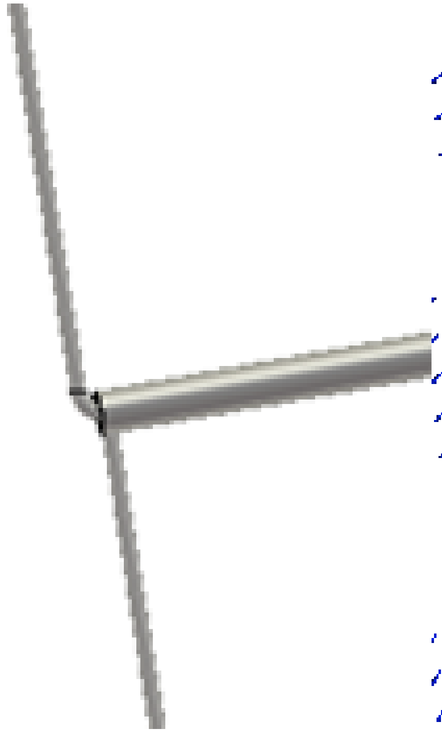
# Dipolos en PCB (distintas L)

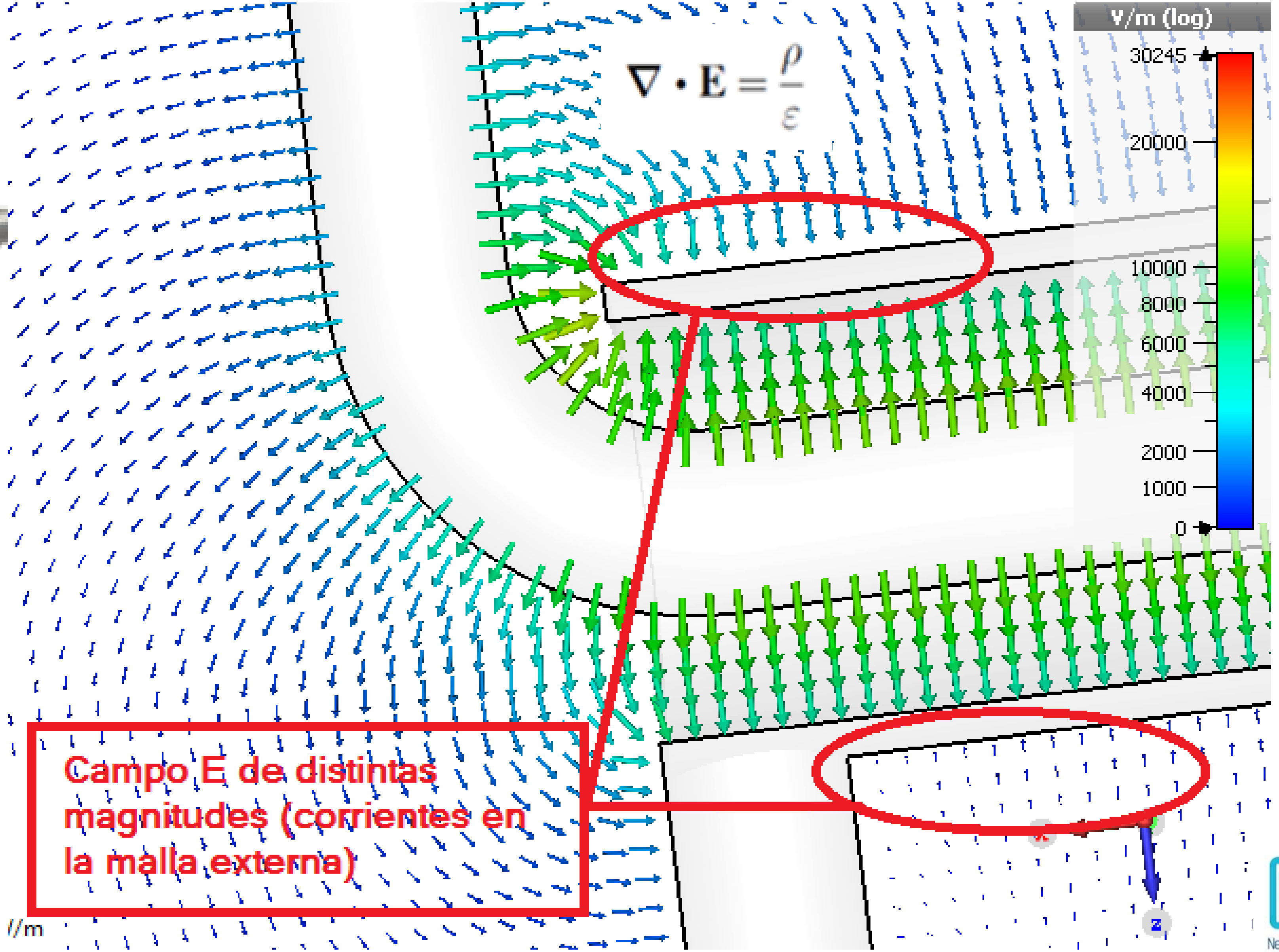


# Dipolos  en PCB



Alimentación de Dipolos



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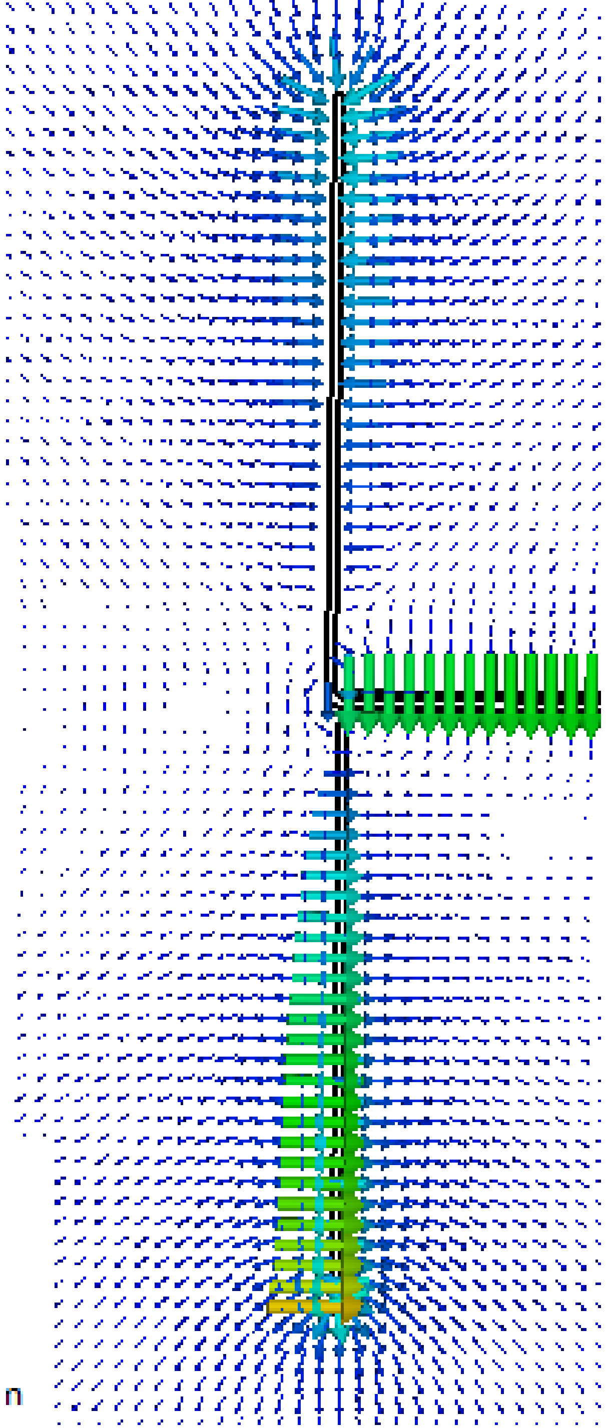
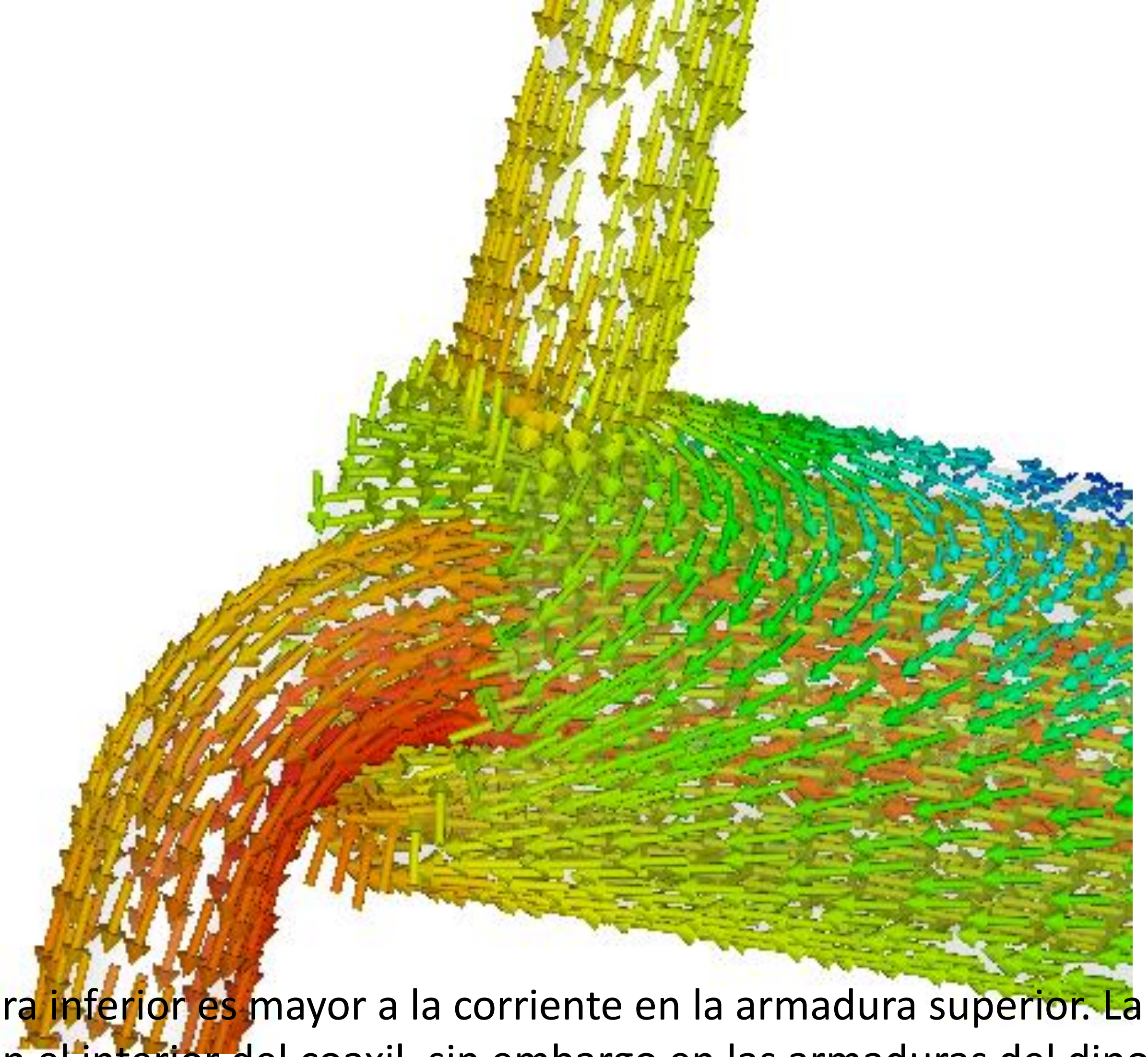
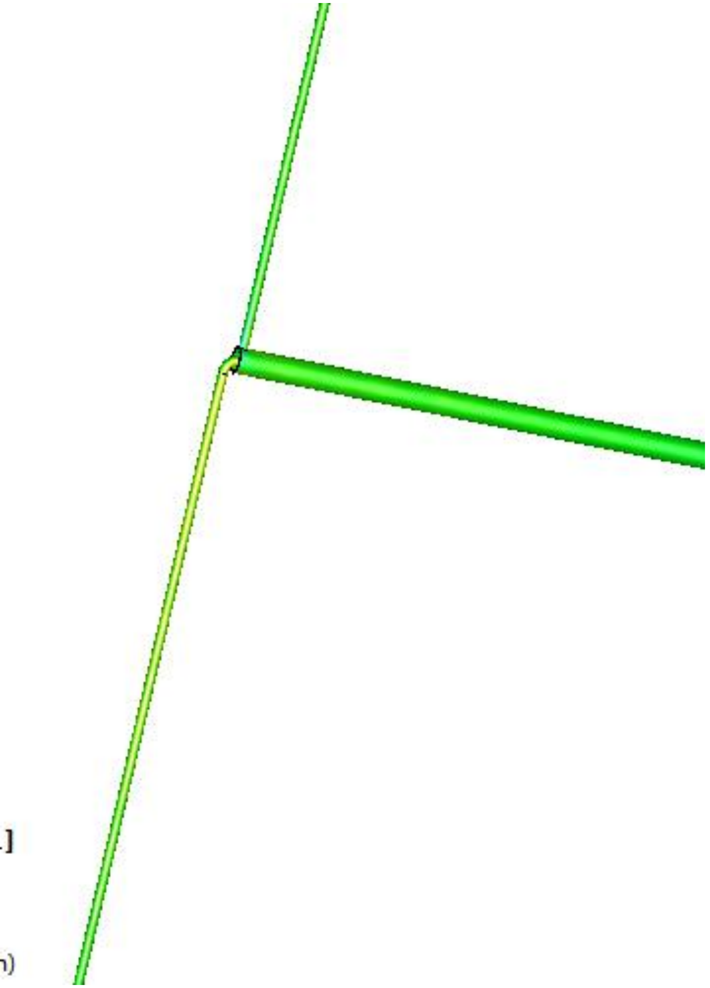
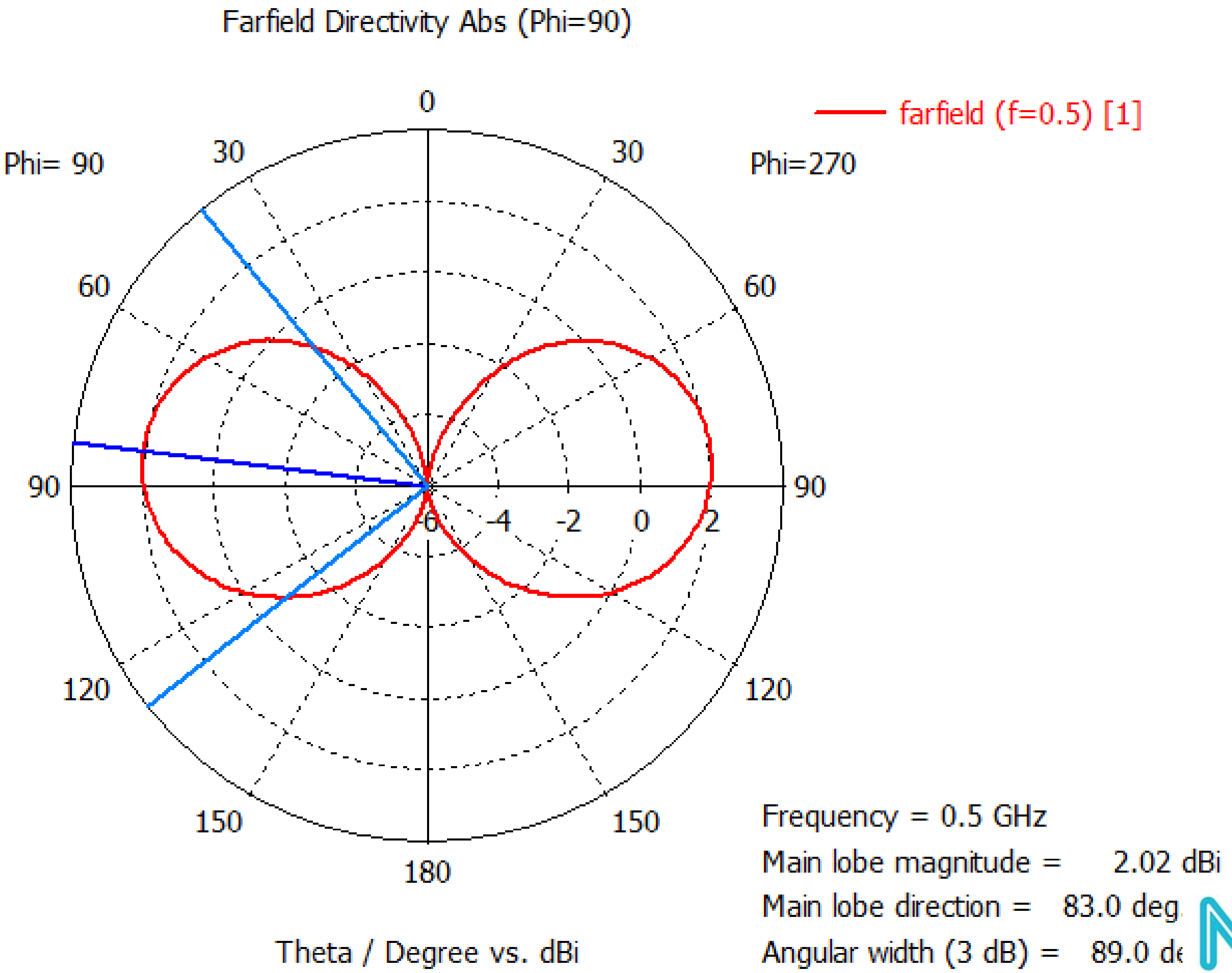




La corriente en la armadura inferior es mayor a la corriente en la armadura superior. La corriente es balanceada en el interior del coaxil, sin embargo en las armaduras del dipolo se desbalancea.

Esa diferencia en las corrientes circula por la cara exterior del coaxil y también irradia.



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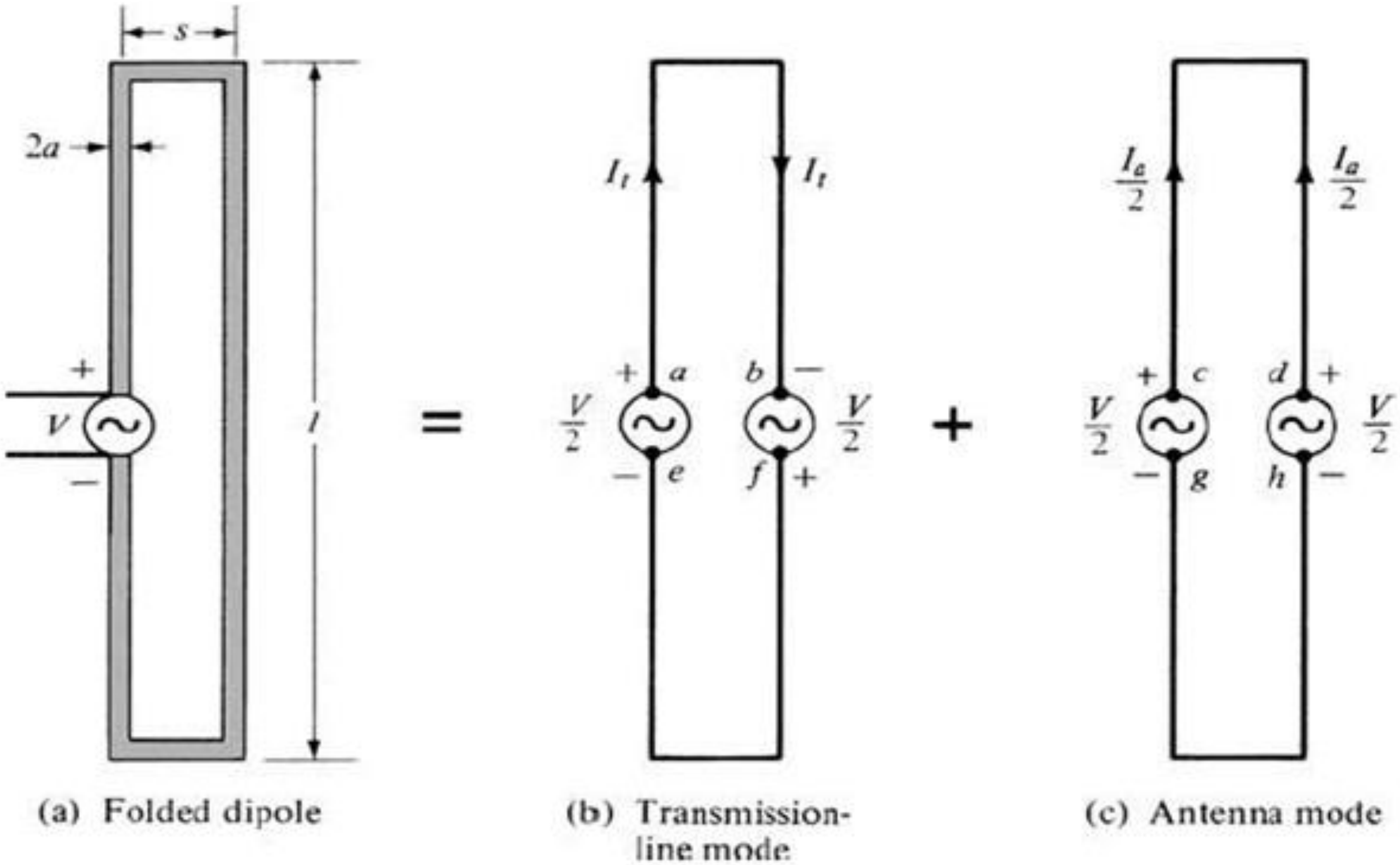
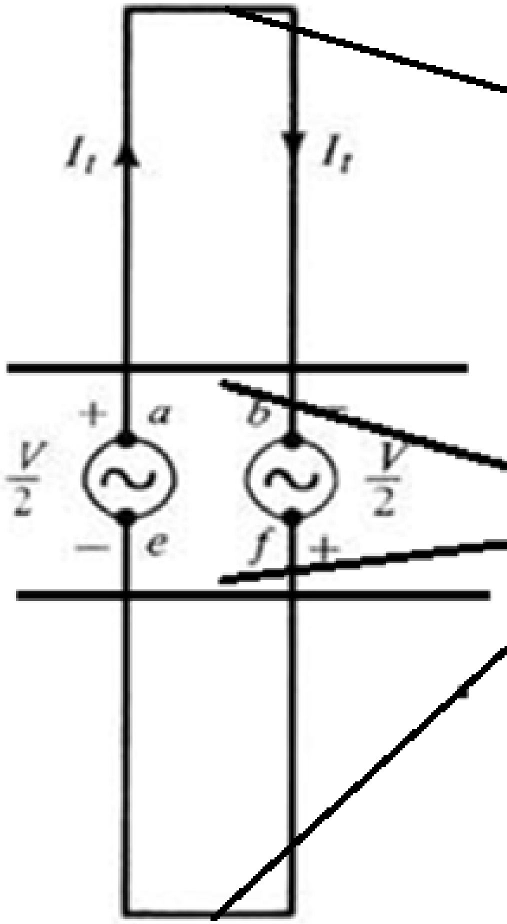
# Dipolo plegado



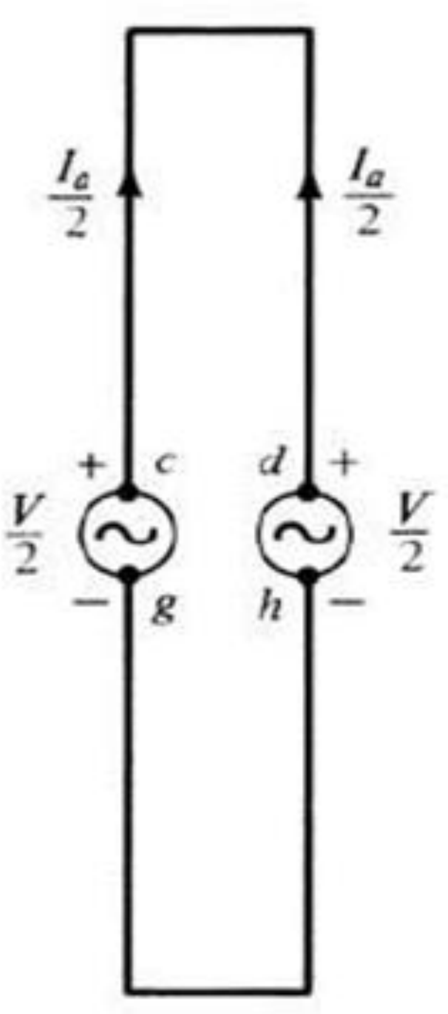




0 (corto circuito)

$$Z_t = Z_0 \left[ \frac{Z_L + jZ_0 \tan(kl')}{Z_0 + jZ_L \tan(kl')} \right]_{\substack{l'=l/2 \\ Z_L=0}} = jZ_0 \tan\left(k\frac{l}{2}\right)$$

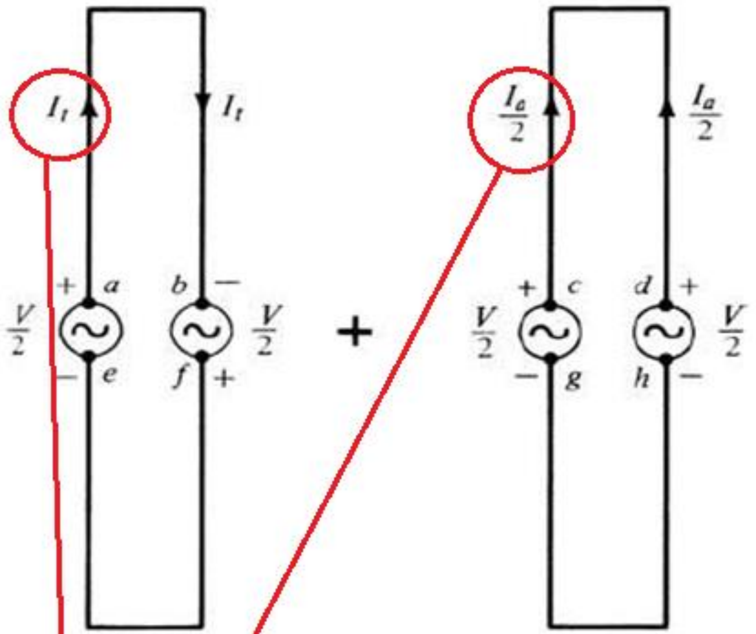
$$\boxed{I_t = \frac{V/2}{Z_t}}$$

# Dipolo plegado




$$I_a = \frac{V/2}{Z_d}$$

Zd es la impedancia de un dipolo de la misma longitud que el dipolo plegado y de espesor igual a la separación de las armaduras

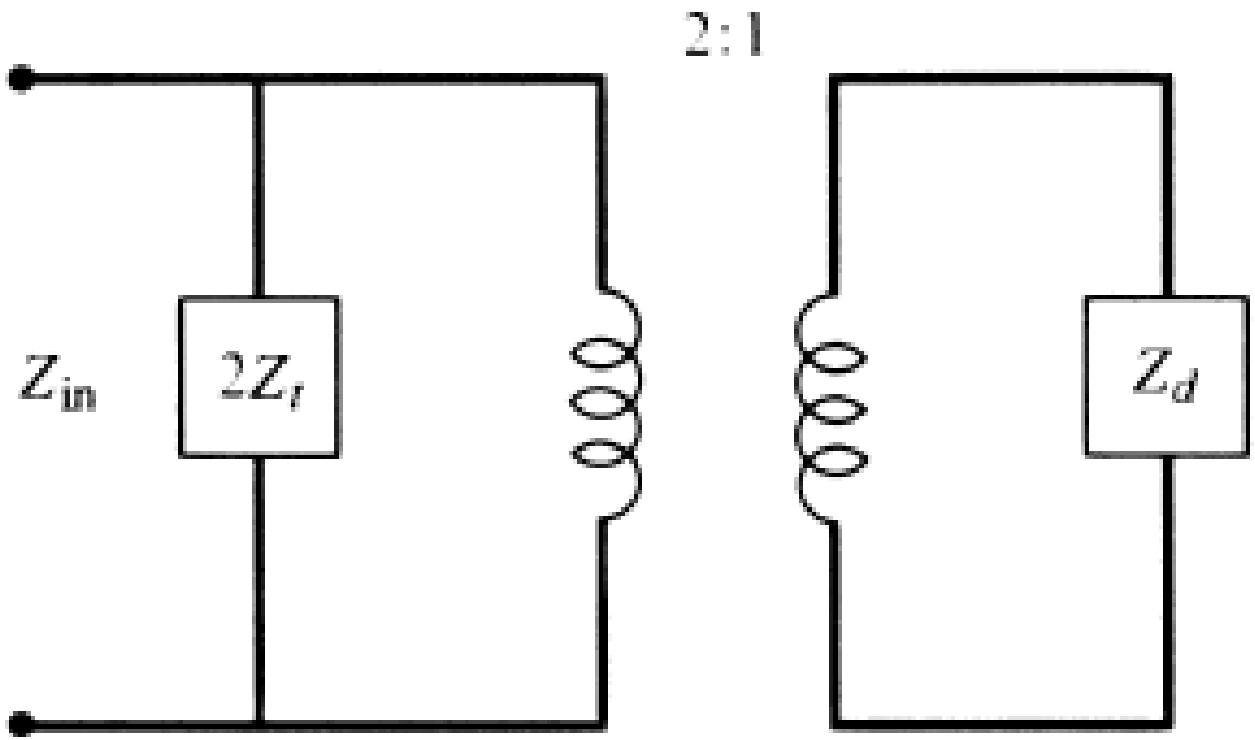



$$I_{in} = I_t + \frac{I_a}{2} = \frac{V}{2Z_t} + \frac{V}{4Z_d} = \frac{V(2Z_d + Z_t)}{4Z_t Z_d}$$

$$\boxed{I_t = \frac{V/2}{Z_t}} \qquad \boxed{I_a = \frac{V/2}{Z_d}}$$

La corriente en los terminales de entrada es la suma de las corrientes de ambas excitaciones.

# Dipolo plegado

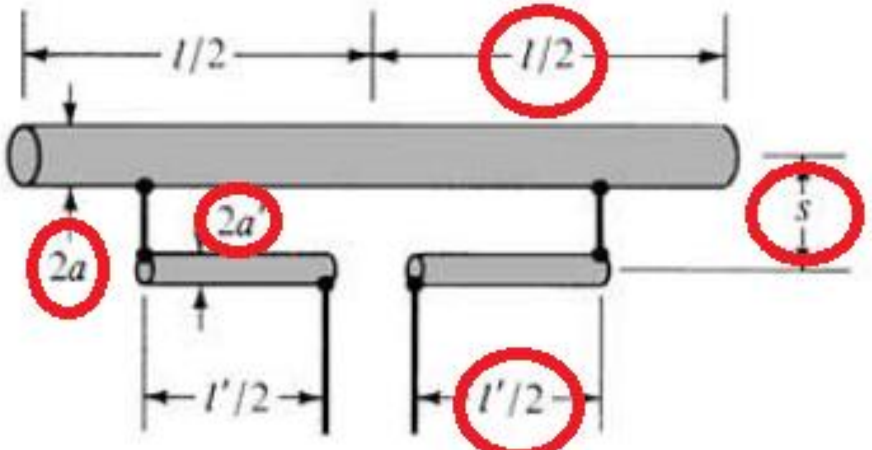



$$Z_{in} = \frac{V}{I_{in}} = \frac{4Z_t Z_d}{2Z_d + Z_t} = \frac{2Z_t(4Z_d)}{2Z_t + 4Z_d}$$

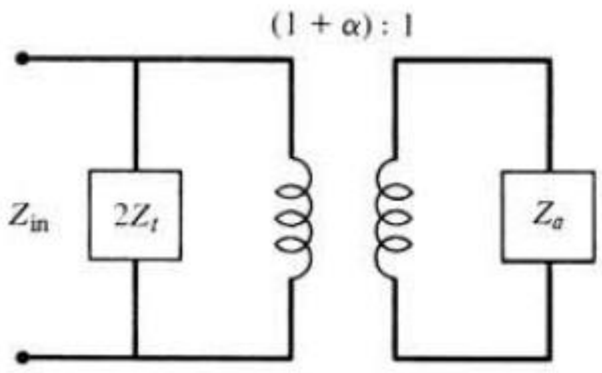
# Adaptadores T y Gamma



# Adaptadores T y Gamma



(a) T-match




$$Z_0 \simeq 276 \log_{10}\left(\frac{s}{\sqrt{aa'}}\right)$$

$$\alpha \simeq \frac{\ln(v)}{\ln(v) - \ln(u)}$$

$$u = \frac{a}{a'}$$

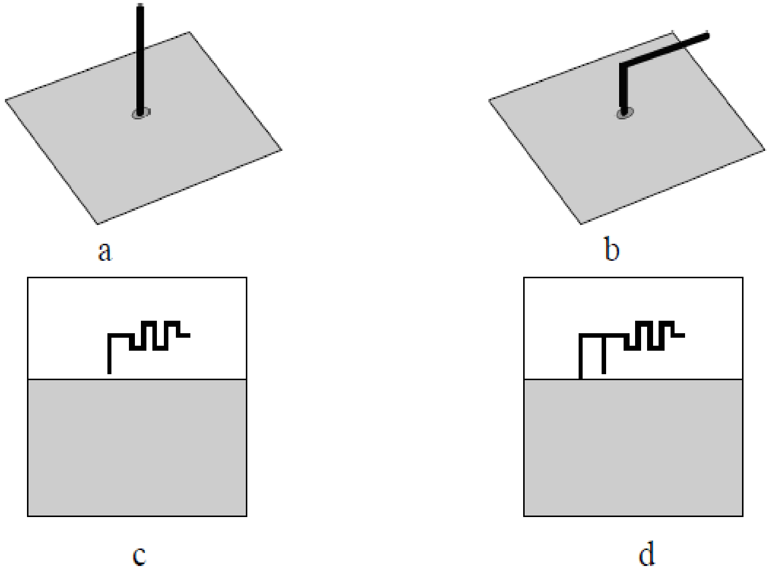
$$v = \frac{s}{a'}$$

$$Z_t = j Z_0 \tan\left(k\frac{l'}{2}\right)$$

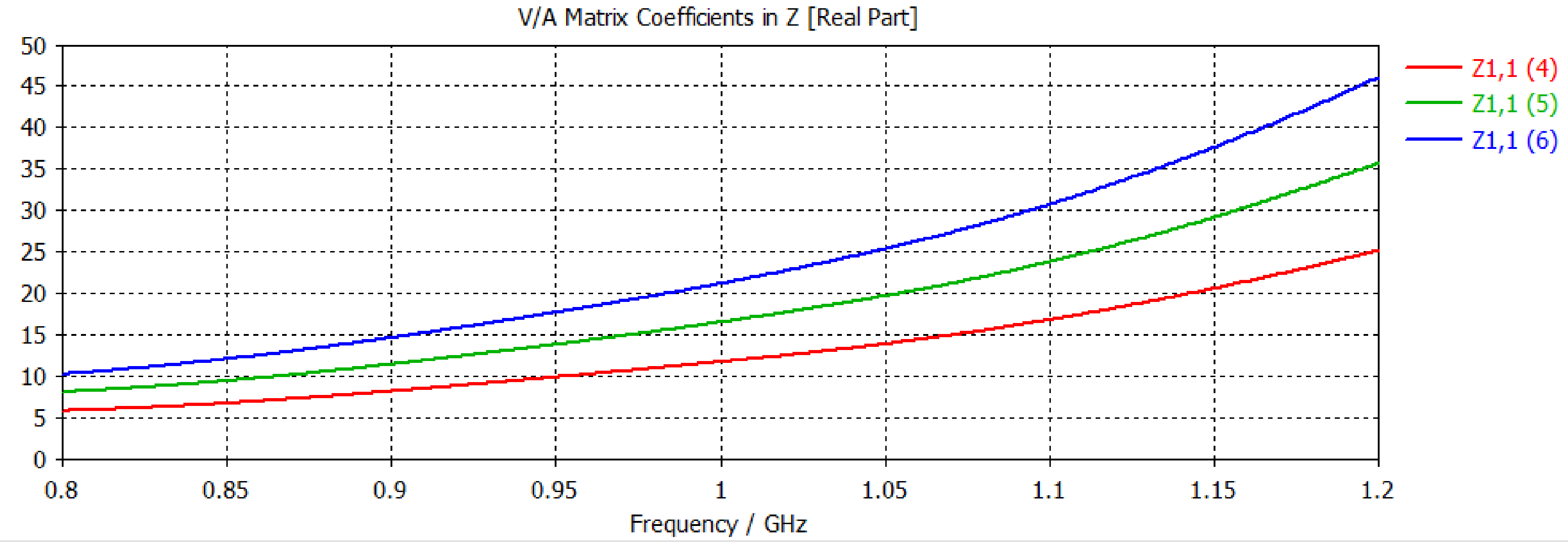
# Antena MIFA

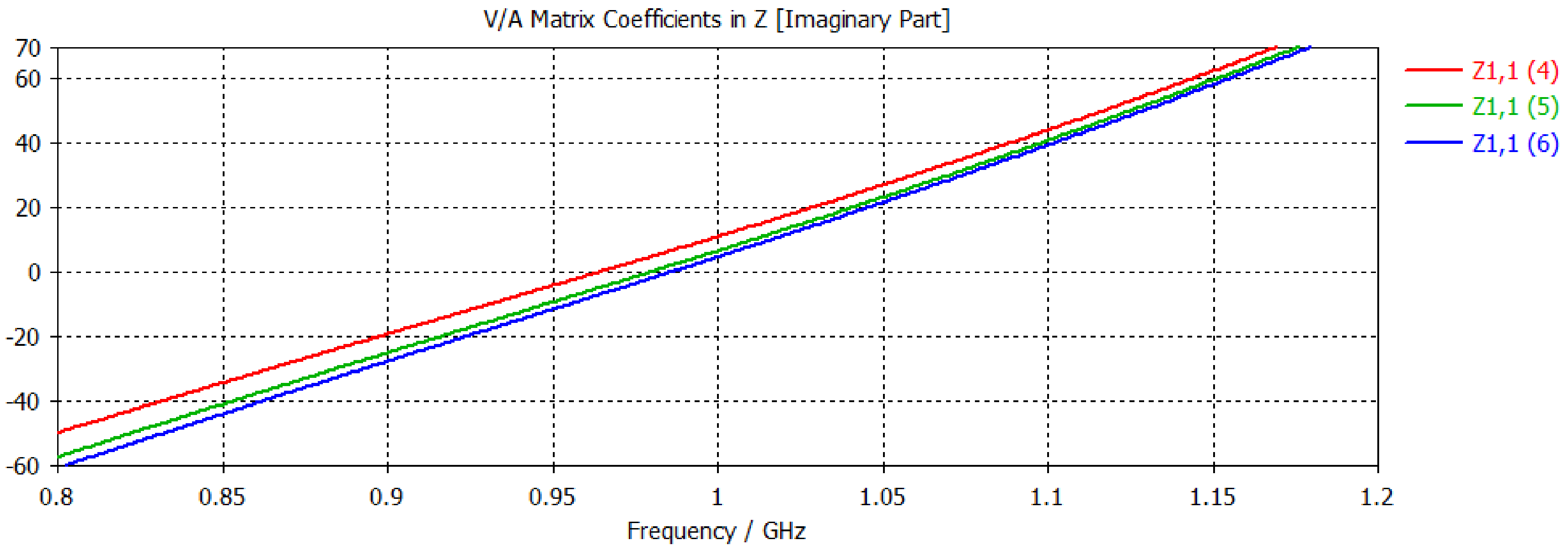

868/915MHz
Texas Instruments Norway AS
CC1110EM


SAMSUNG


a
b
c
d

# L invertida (L total 113/2mm H=10, 15 y 20 mm

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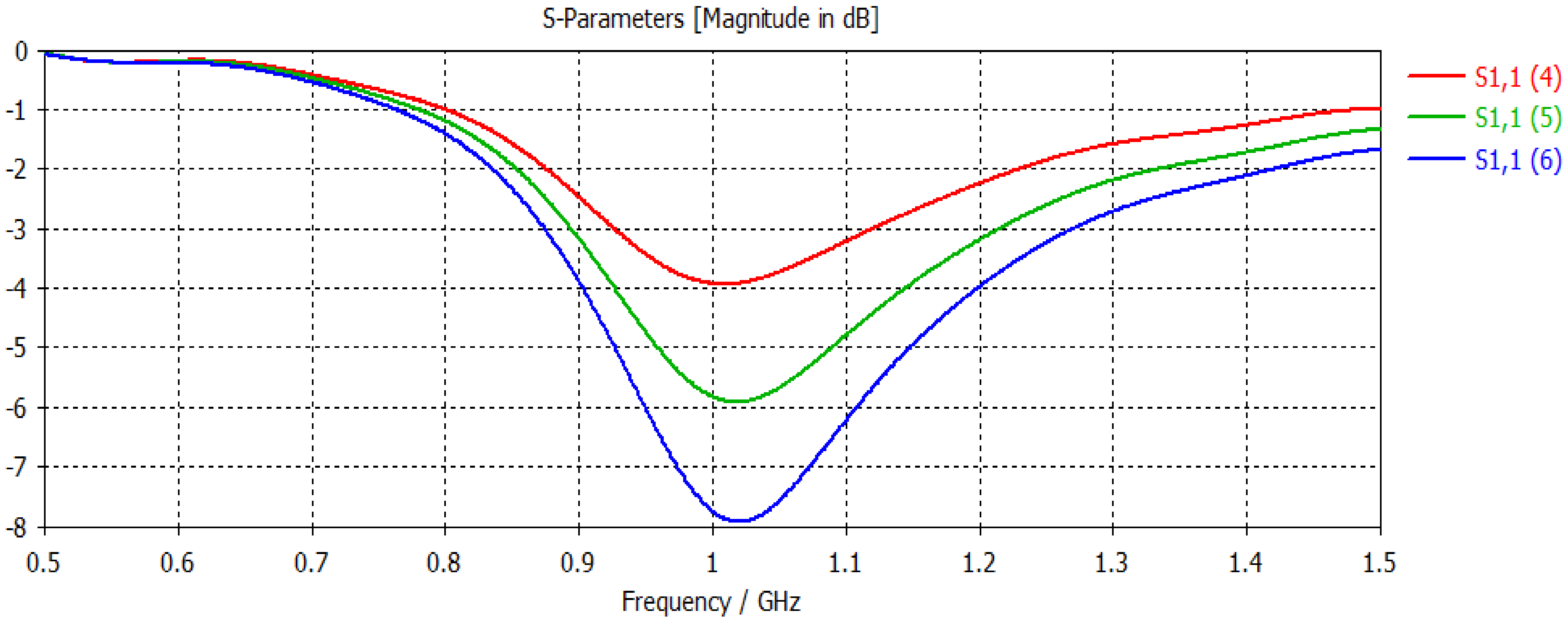
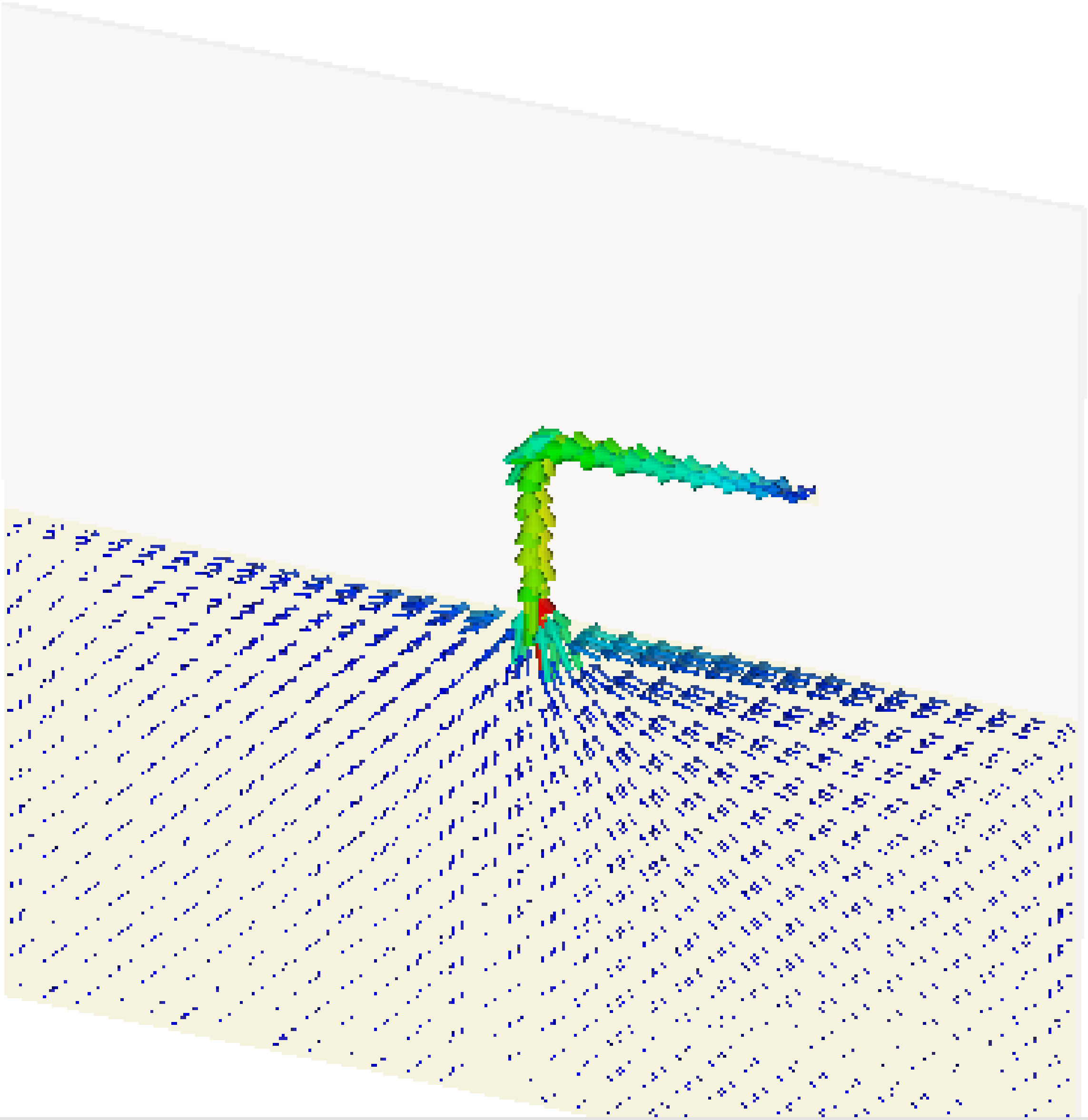
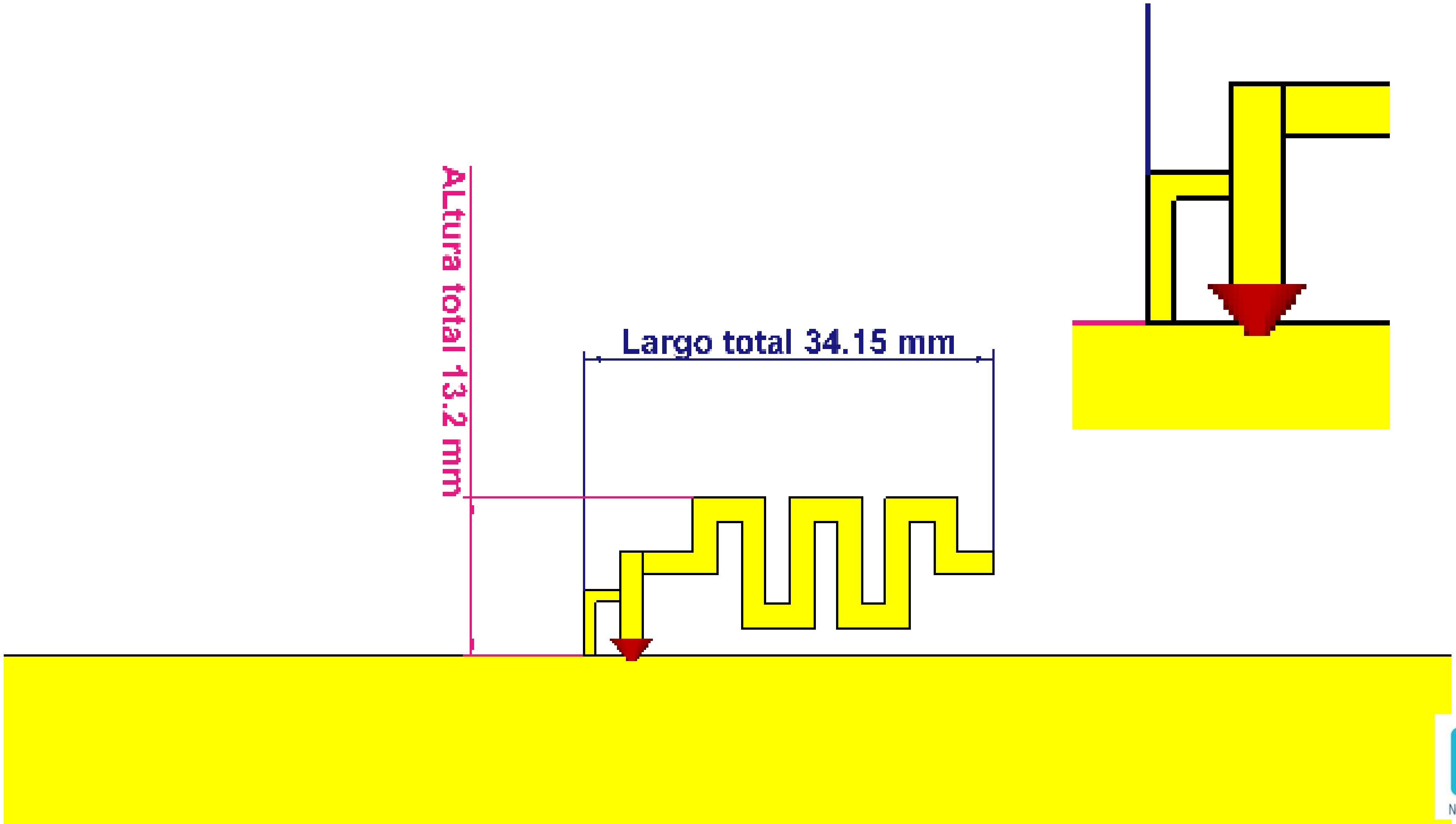
# L invertida (L total 113/2mm H=10, 15 y 20 mm



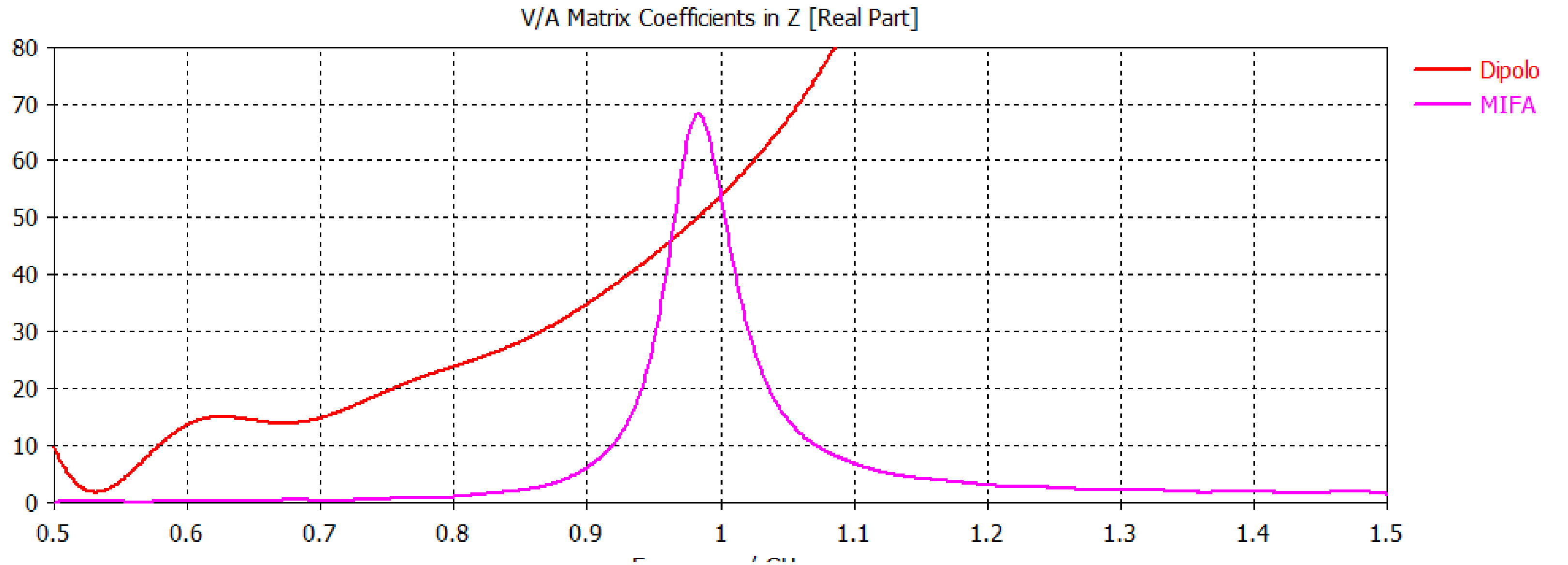
# L invertida Vector corriente J

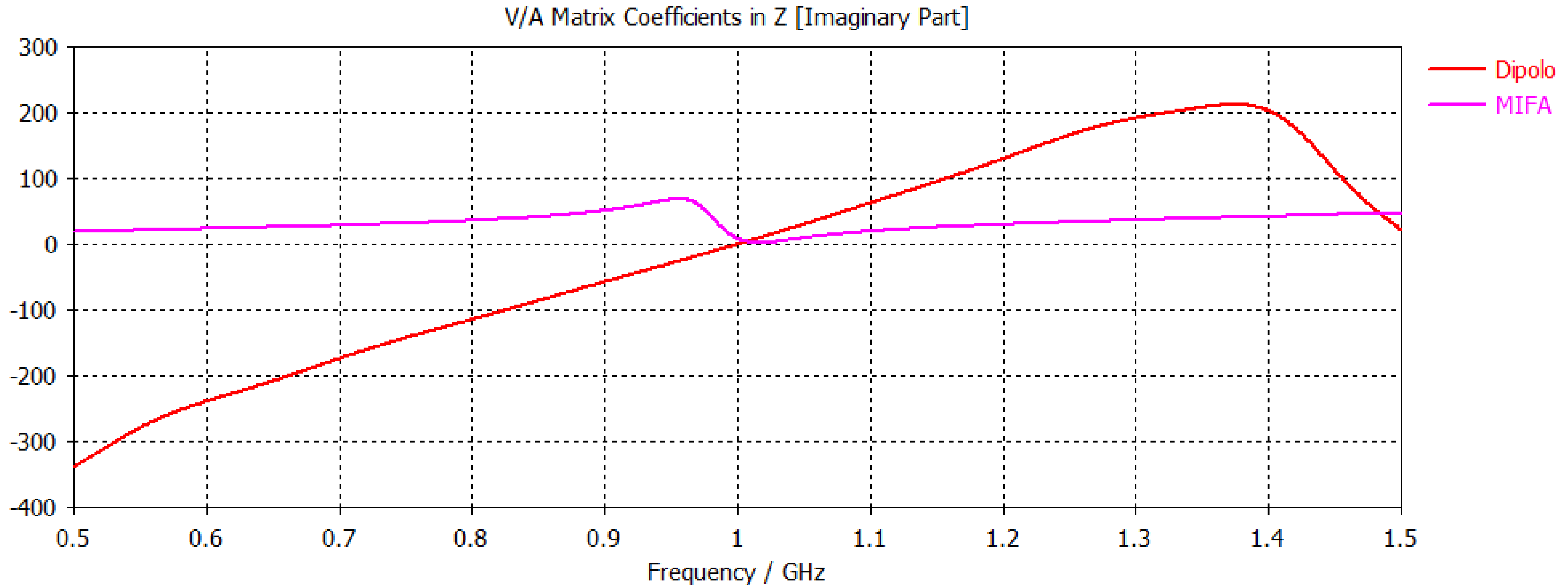


# MIFA

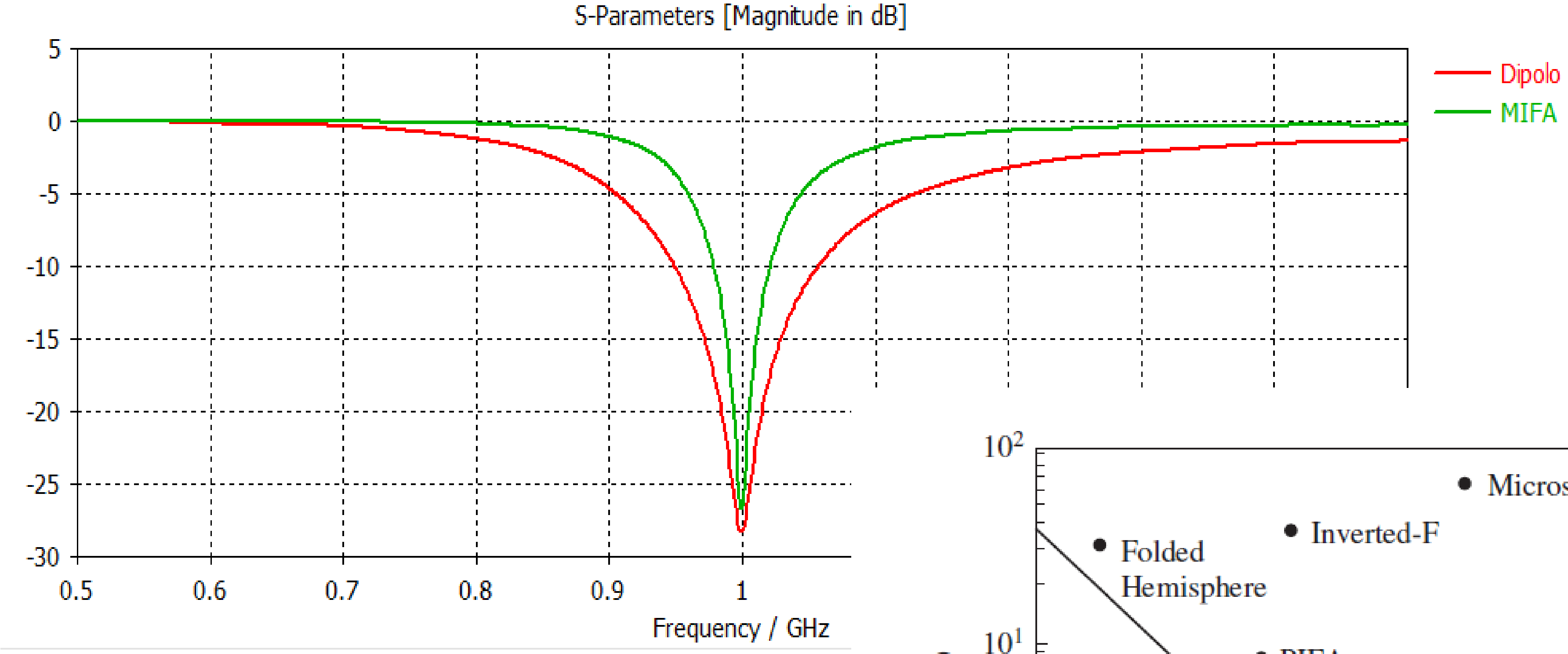


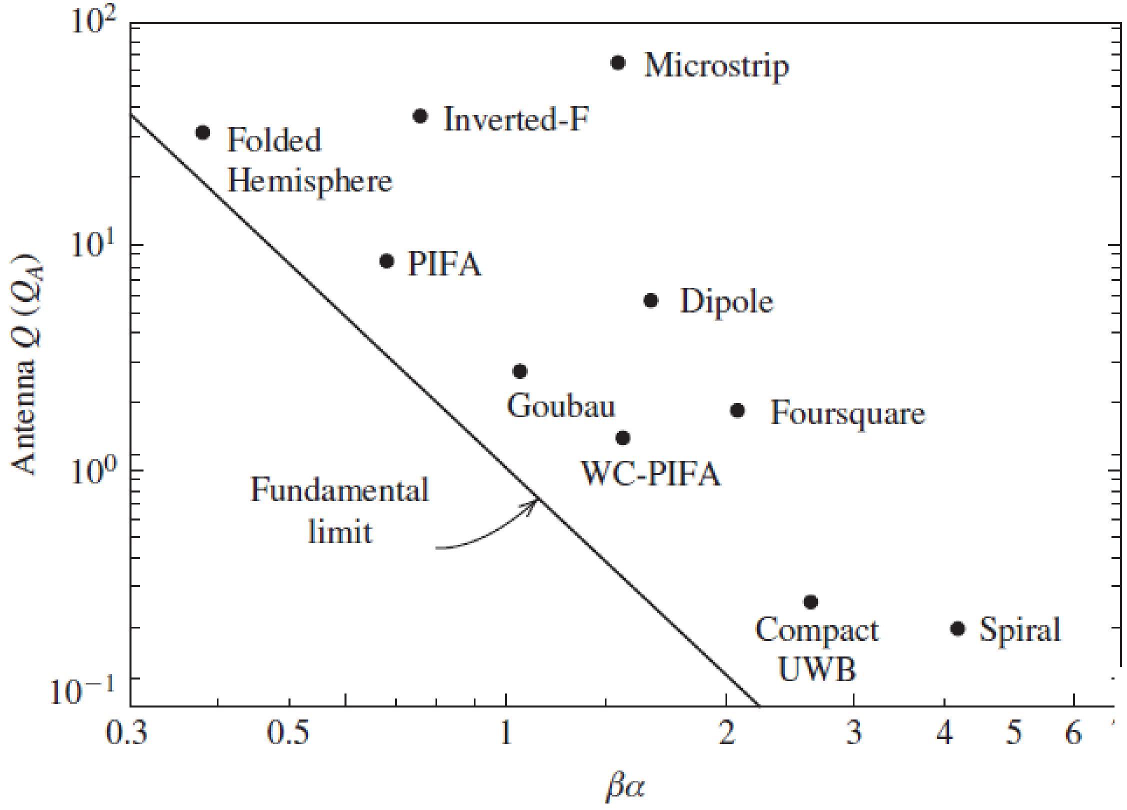
# MIFA


V/A Matrix Coefficients in Z [Real Part]
80
70
60
50
40
30
20
10
0
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Dipolo
MIFA


V/A Matrix Coefficients in Z [Imaginary Part]
300
200
100
0
-100
-200
-300
-400
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Frequency / GHz
Dipolo
MIFA

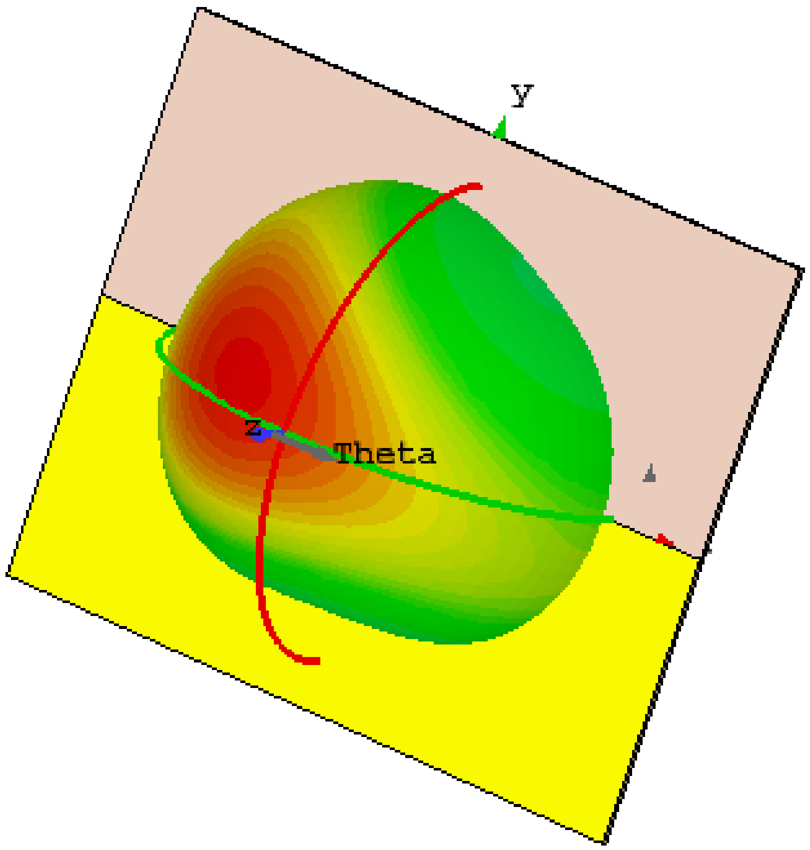
# MIFA




Disminuir el tamaño de una antena es hacerla más reactiva y de menor ancho de banda.

# Patrón campo lejano MIFA




```
Type          = Farfield
Approximation = enabled (kR >> 1)
Monitor       = farfield (f=1) [1]
Component     = Abs
Output        = Directivity
Frequency = 1 GHz
Rad. effic.   = -1.014 dB
Tot. effic.   = -1.021 dB
Dir.          =  2.315 dBi
```

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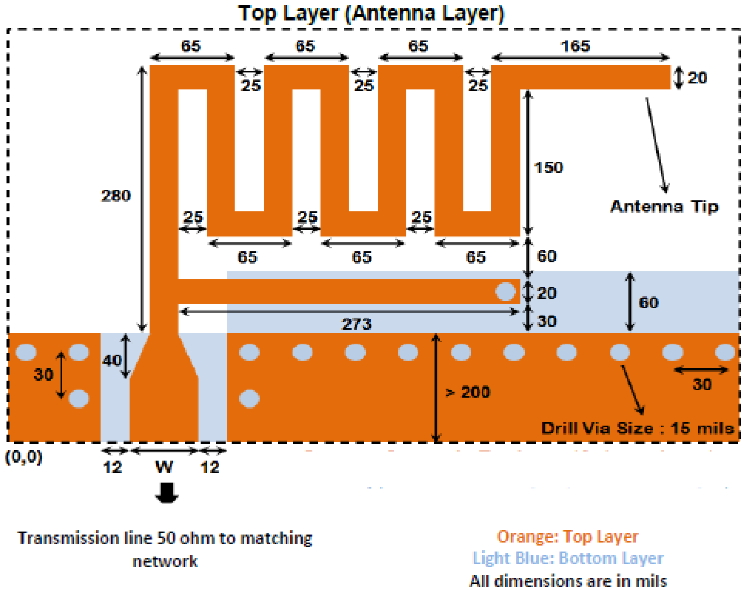
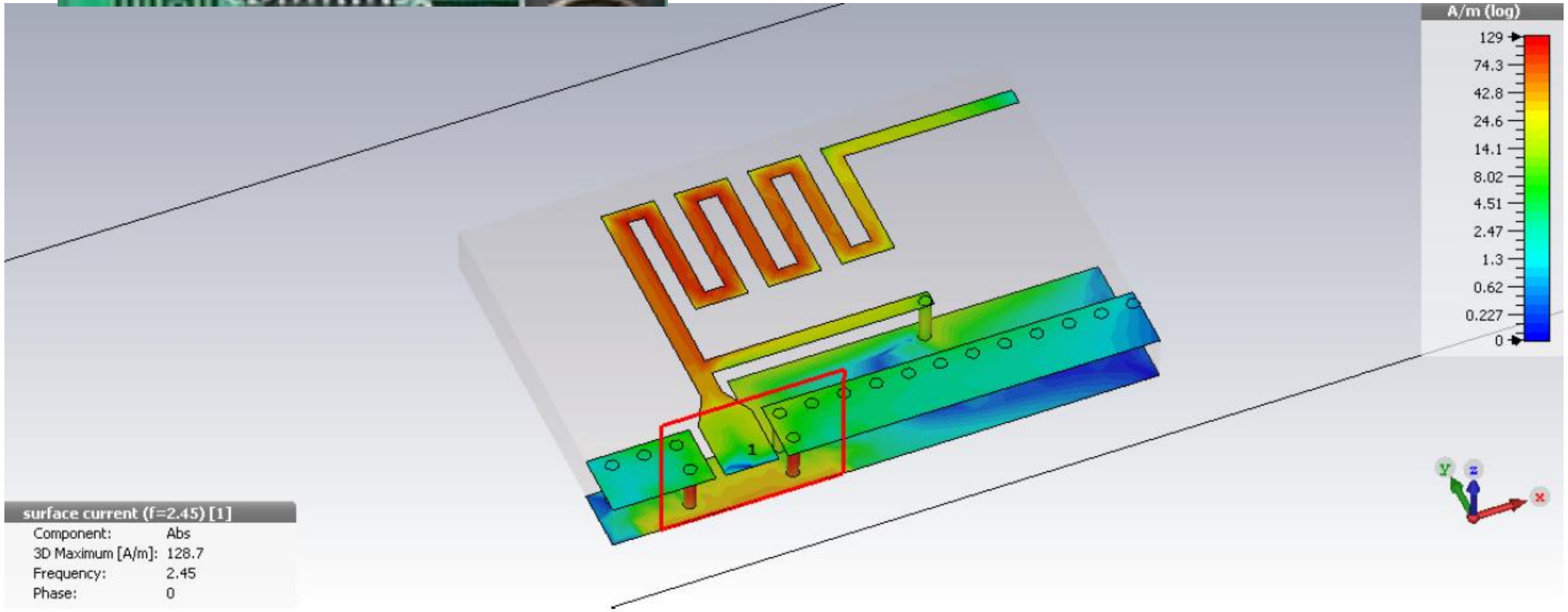
CYPRESS
EMBEDDED IN TOMORROW™

AN91445


Figure 10. MIFA Layout

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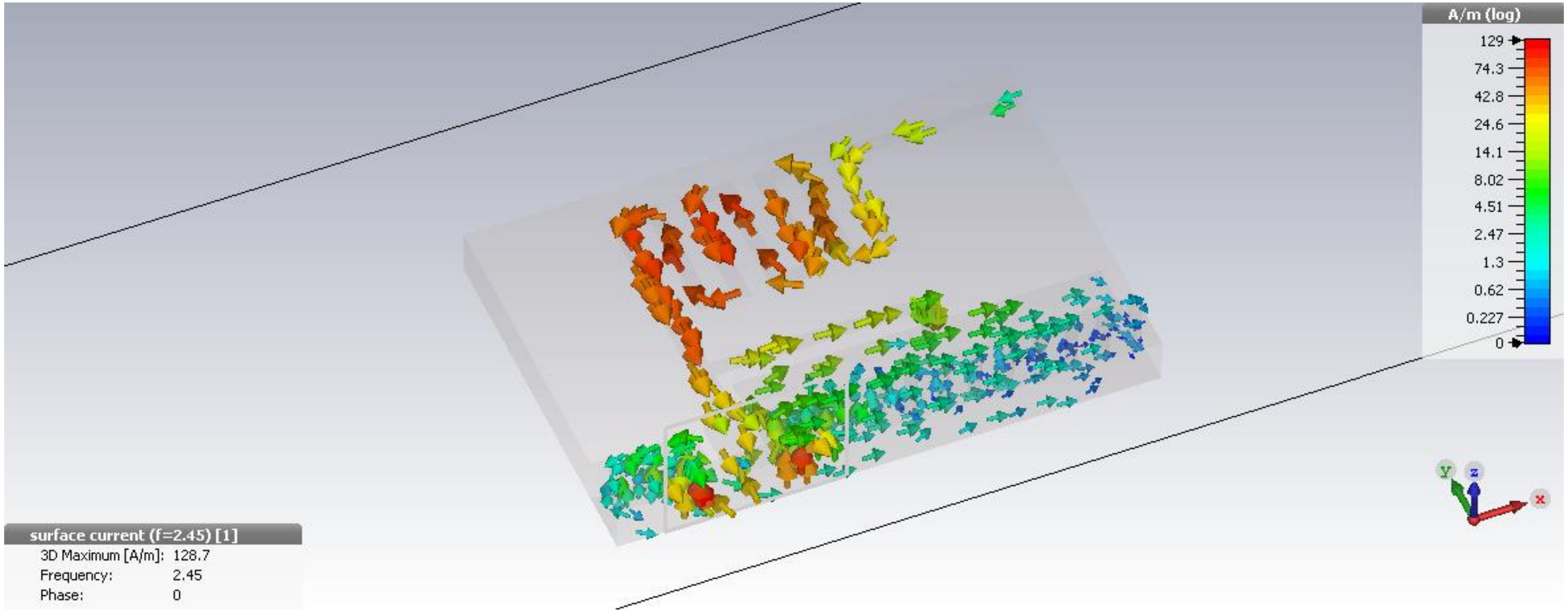
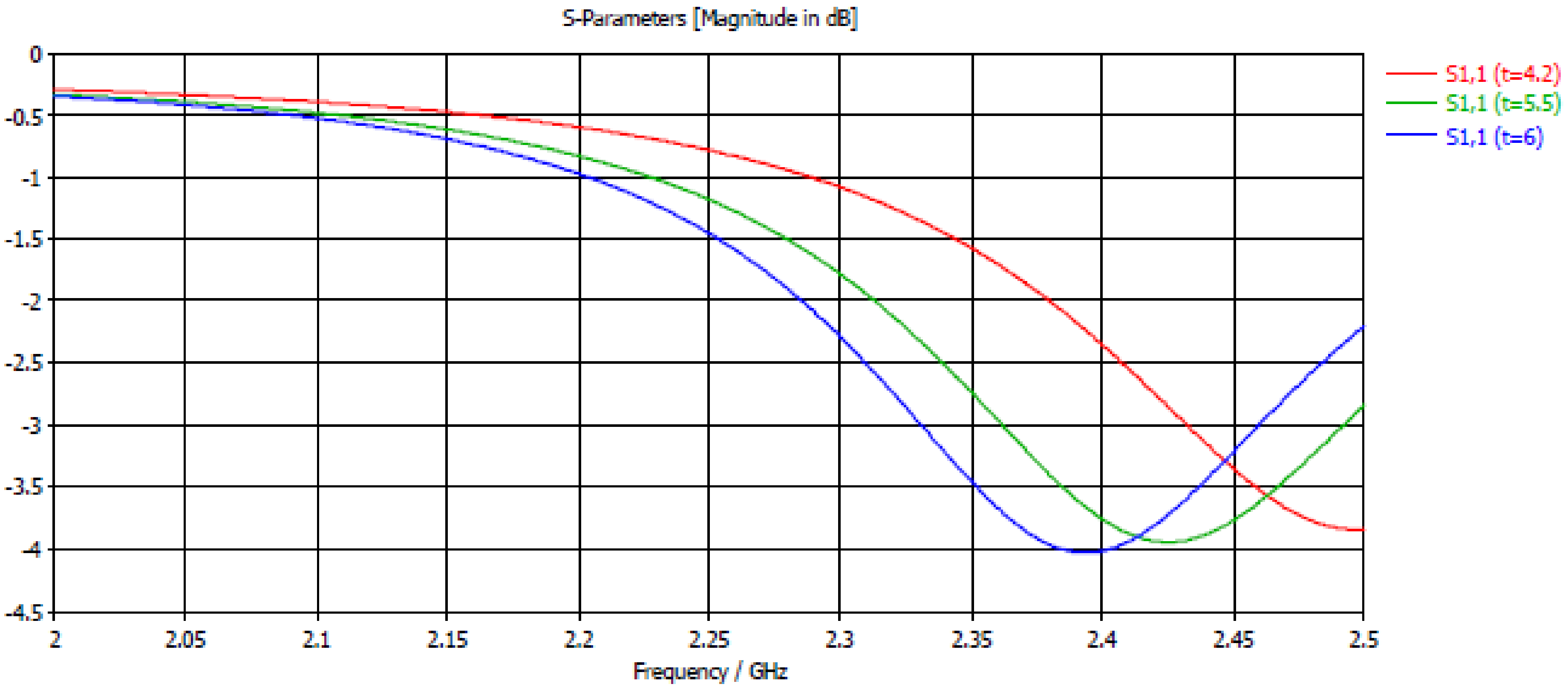

A/m (log)
129
74.3
42.8
24.6
14.1
8.02
4.51
2.47
1.3
0.62
0.227
0
surface current (f=2.45) [1]
3D Maximum [A/m]: 128.7
Frequency: 2.45
Phase: 0
y
z
x

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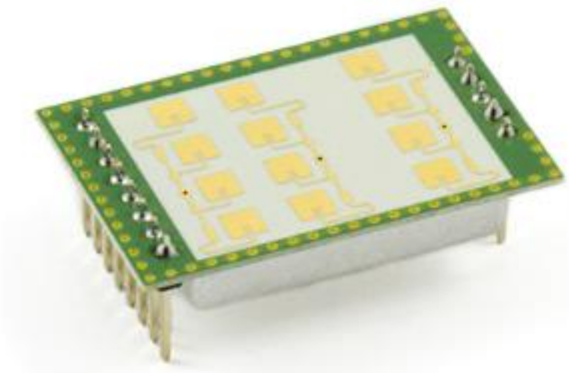

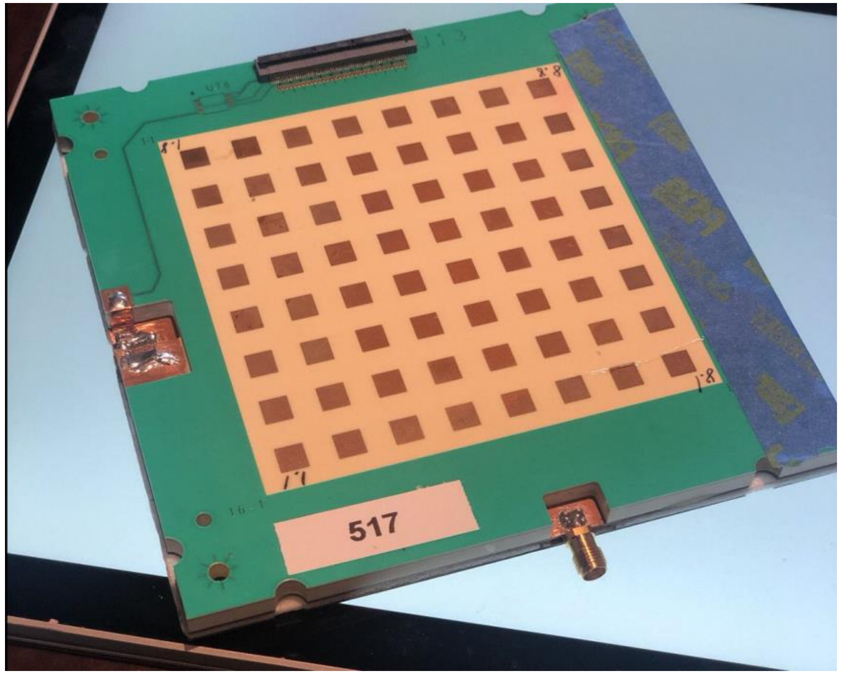


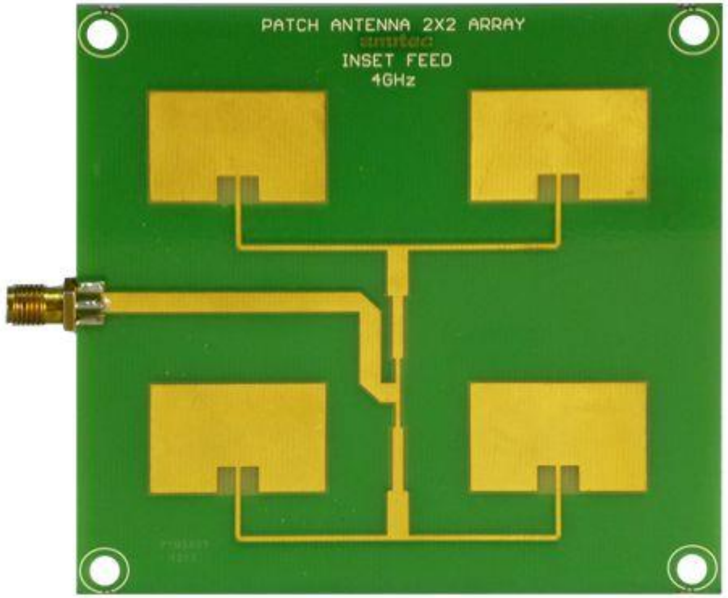


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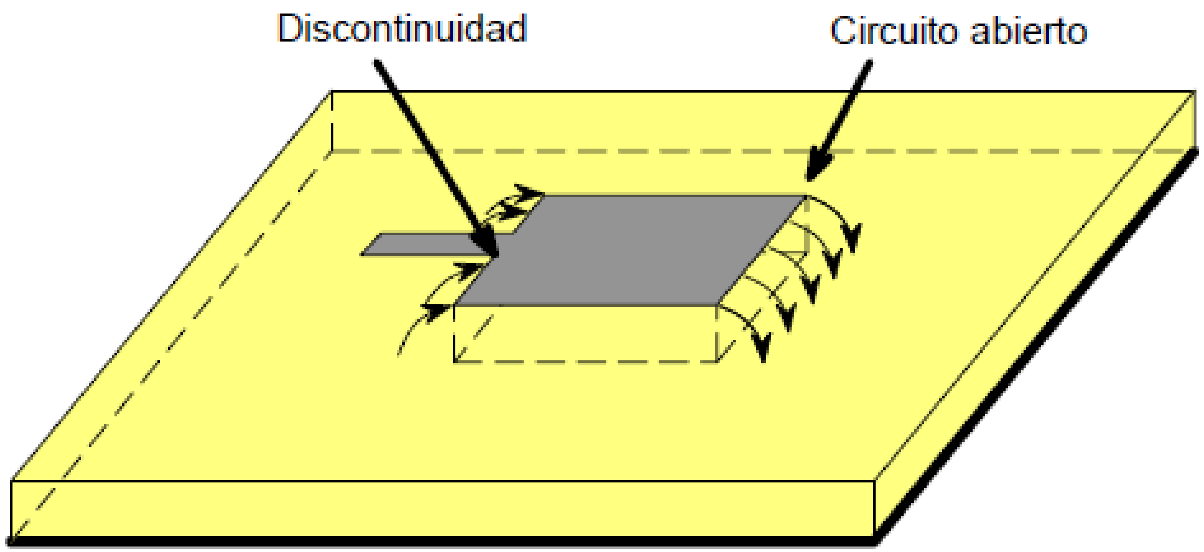


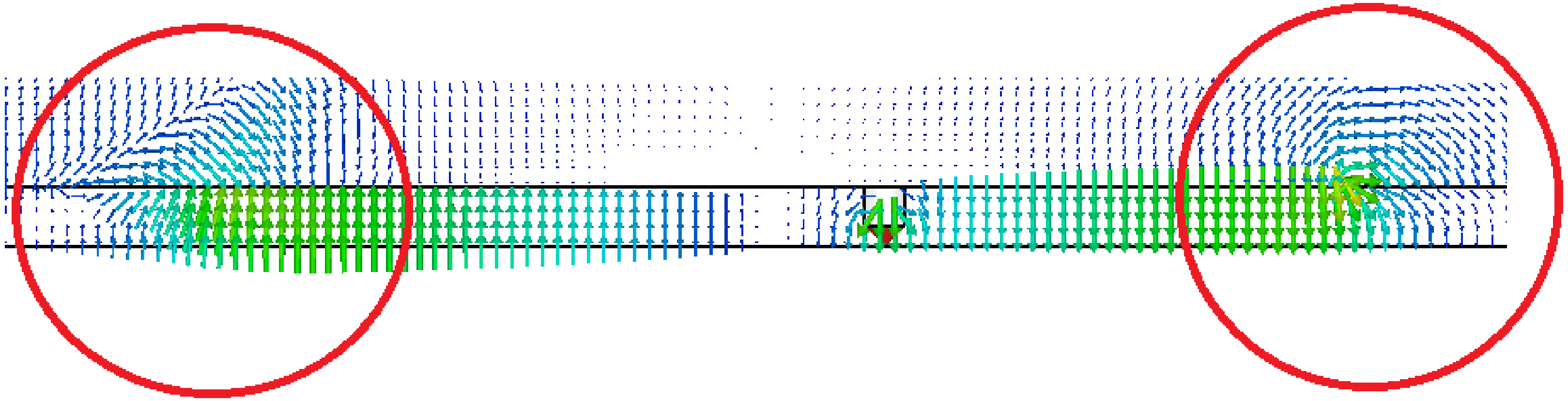

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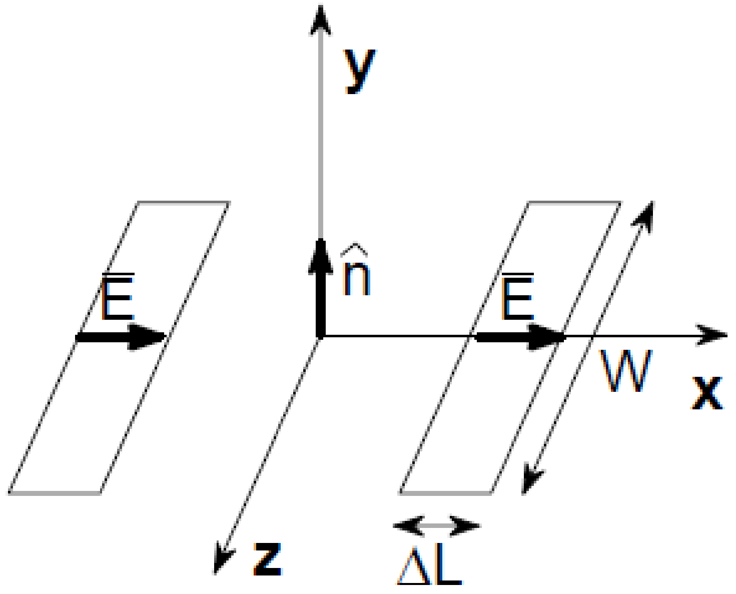
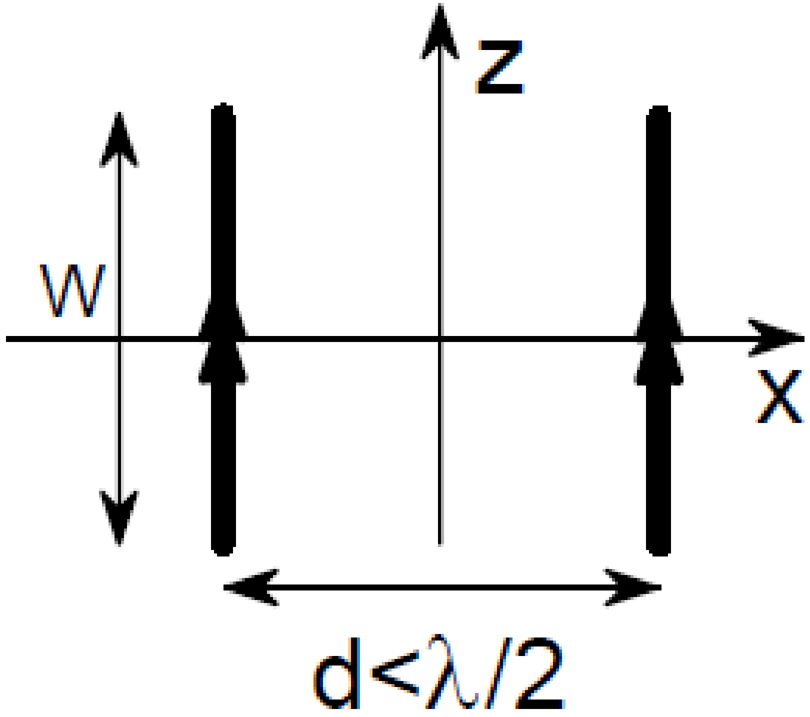
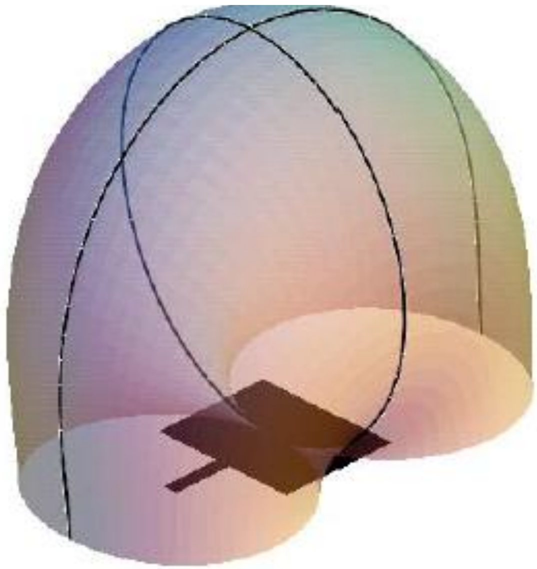
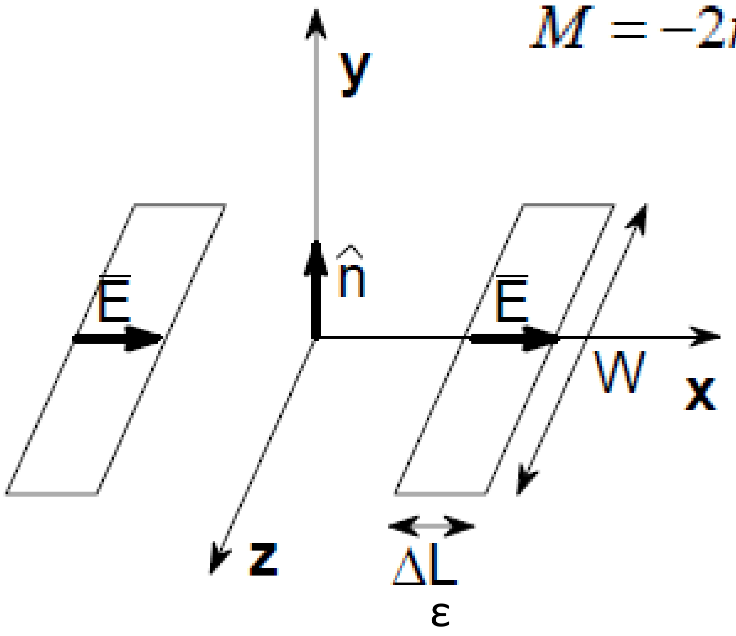


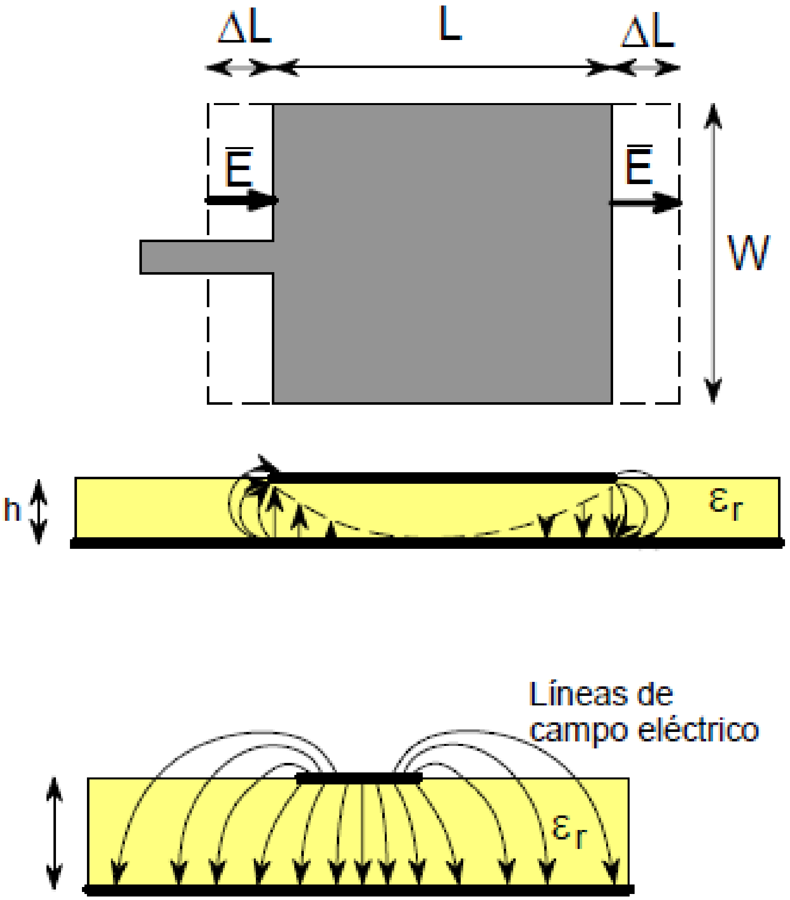
EL campo de los dos dipolos magnéticos separados media longitud de onda se suman en la dirección perpendicular al plano de tierra.

$$\vec{M} = -2\hat{n} \times \vec{E}$$

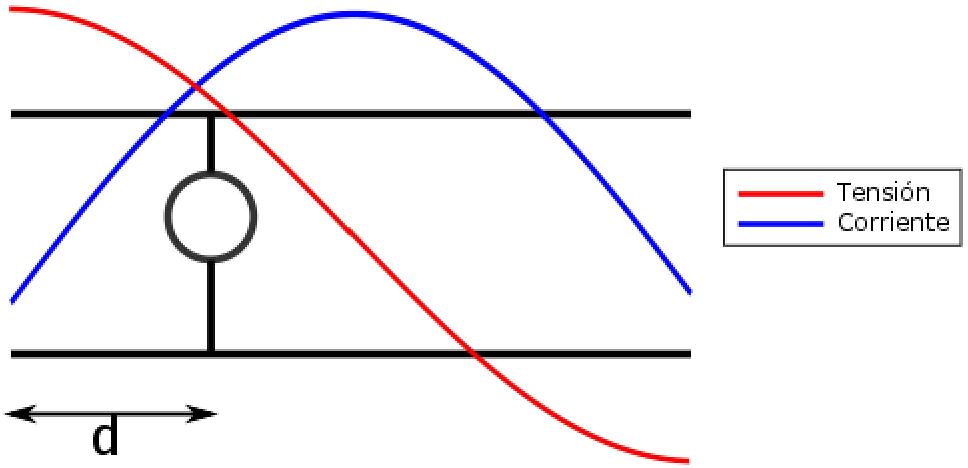


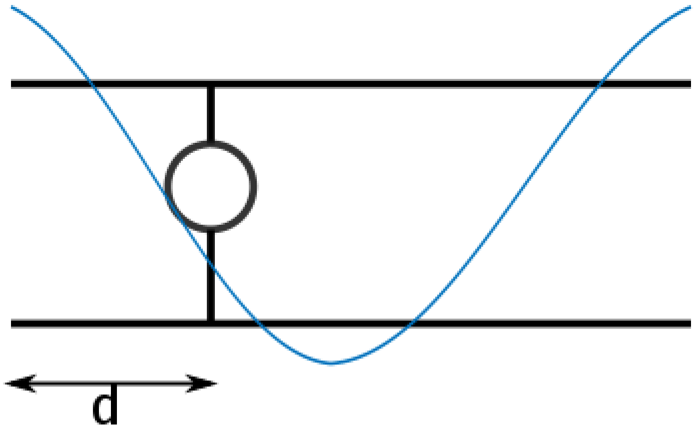

ΔL depende del ε del material dieléctrico y de su espesor. Elevados ε concentran el campo en el dieléctrico y disminuyen el ΔL. Cuanto mayor es la separación entre el patch y la tierra mayor es el ΔL.
A mayor ΔL mayor ancho de banda tiene la antena (efecto dipolo grueso).

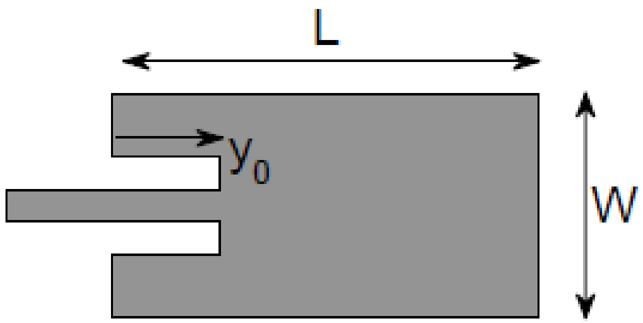
$$\Delta L = 0.412 \, \frac{(\varepsilon_{re} + 0.3)\left(\frac{W}{t} + 0.264\right)}{(\varepsilon_{re} - 0.258)\left(\frac{W}{t} + 0.8\right)} \, t$$

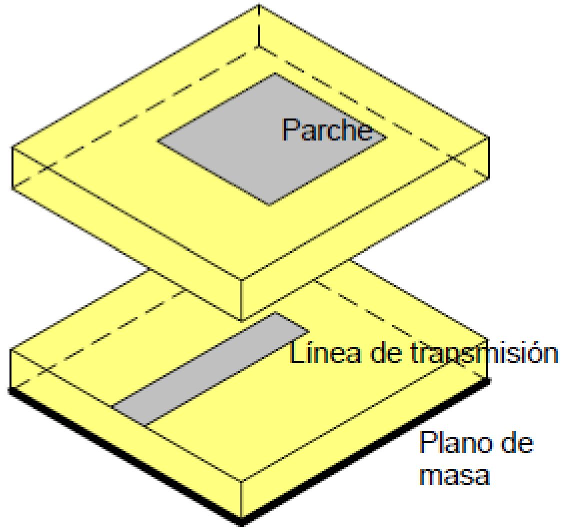


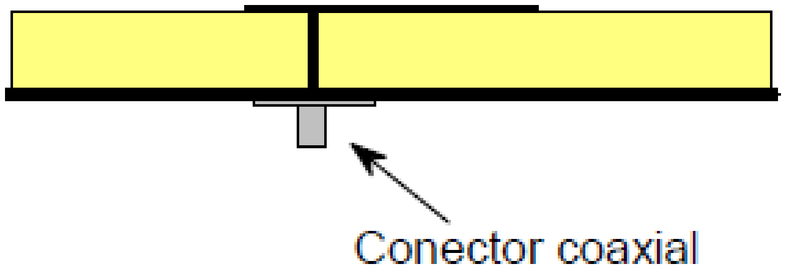

El ΔL determina cuanto se debe acortar la longitud del patch respecto de λ/2 a la frecuencia de trabajo.

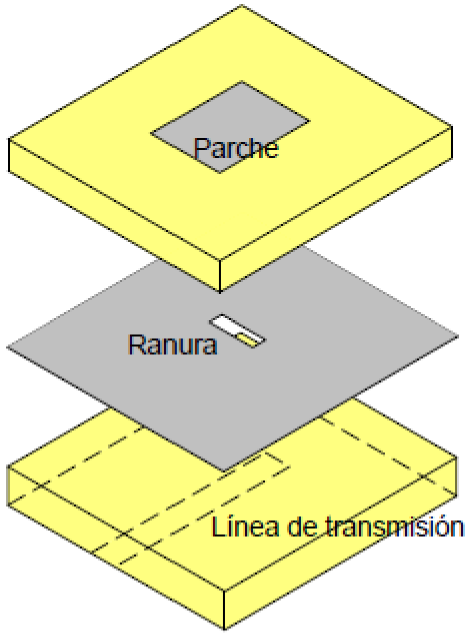

Tensión
Corriente
d


d

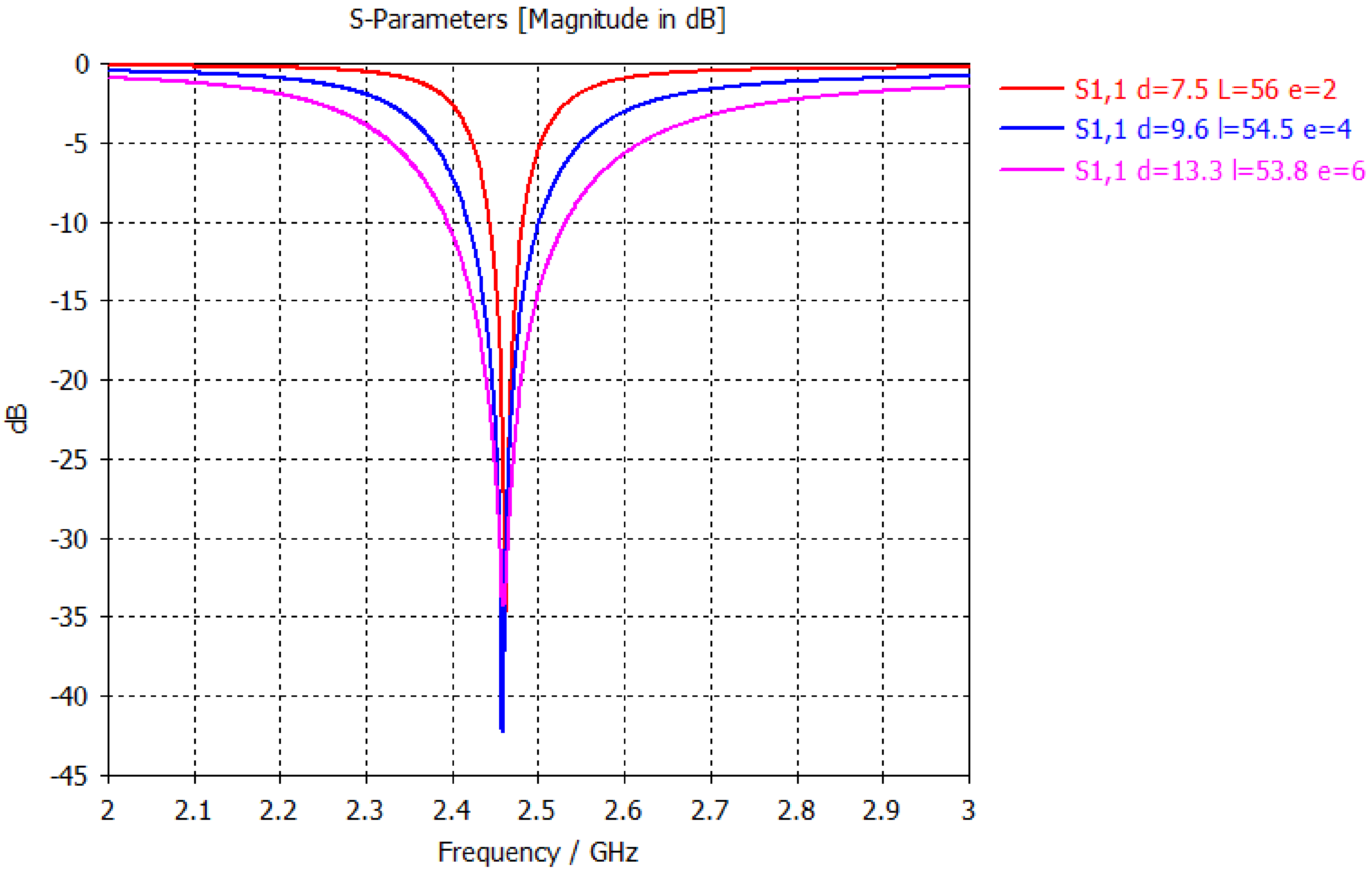

L
y0
W


Parche
Línea de transmisión
Plano de masa

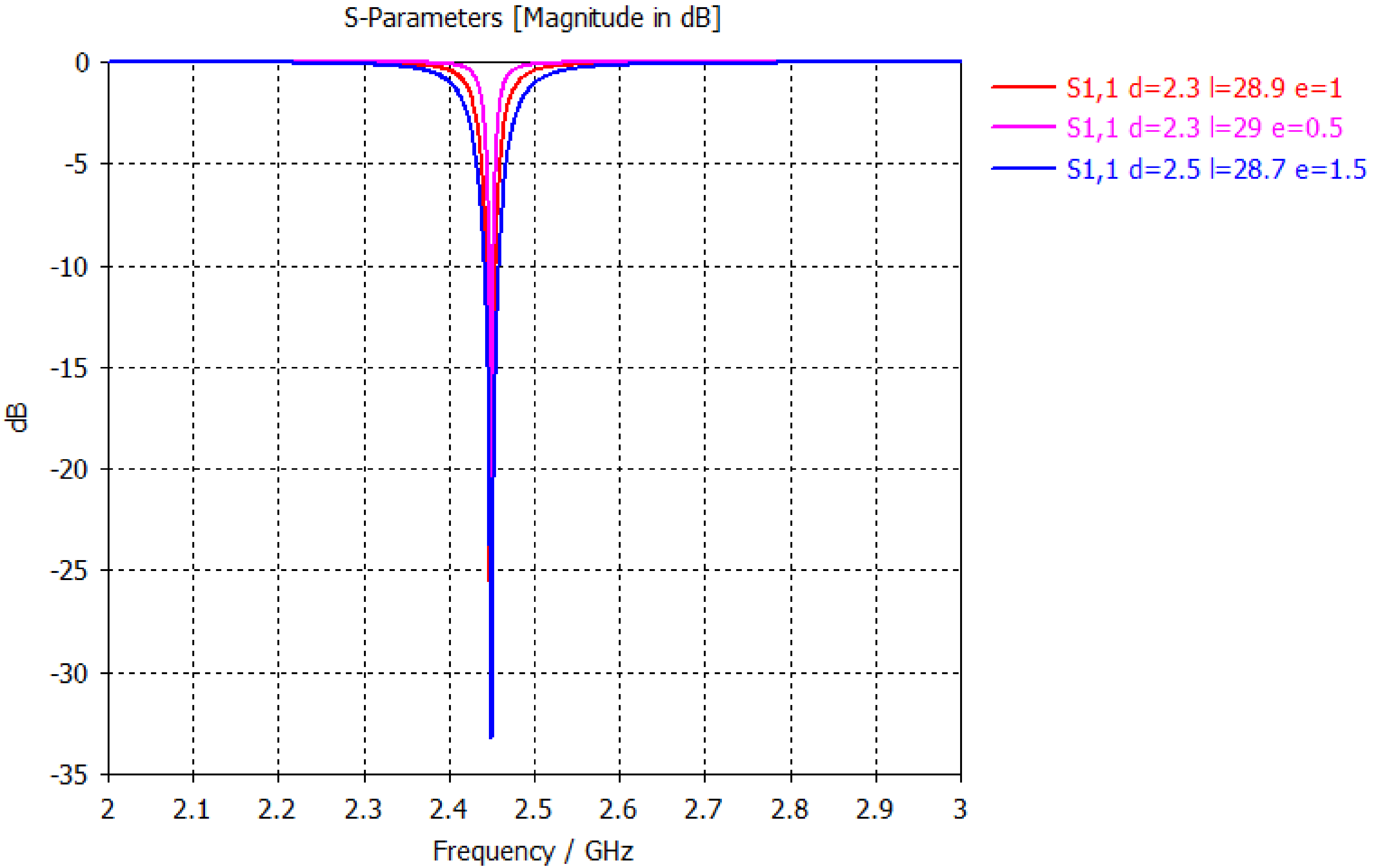

Conector coaxial


Parche
Ranura
Línea de transmisión

Coeficiente de reflexión de antena patch metálica con dieléctrico aire y alimentación por "pin" para diferentes separaciones entre patch y plano de tierra y distancias del pin de alimentación al centro del patch.



Coeficiente de reflexión de antena patch metálica con alimentación por "pin" y sustrato FR-4 para diferentes separaciones entre patch y plano de tierra y distancias del pin de alimentación al centro del patch.

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