Near and far Field Measurements for EMC

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Outline of the Presentation

- Introduction: Why is important?
- What is Far Field and Near Field.
- Ideal Electric and Magnetic Dipole
- Electric and Magnetic Field Probes
- Measurement of Half Wave Dipole
- Measurement of Shielding

Introduction: Why is important? Far Field Applications

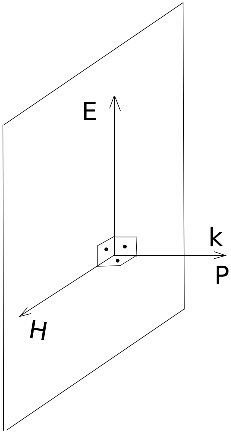
Antenna Measurements
Radiation Pattern
Antenna factor, Rrad, Gain, Effective Area and Length.
Shielding Measurements
Electric and magnetic Field Measurements
Radiating Fields Measurements
Friis equation (Energy conservation)

Introduction: Why is important? Near Field Applications

Near field and far field conditions are important in EMC testing.

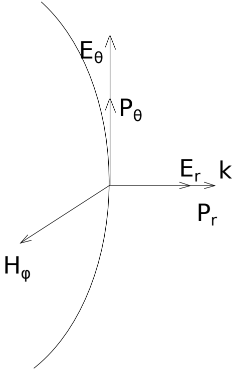
- Shielding tests
- EM Leakage on enclosures
- EM Leakage on cables and connectors
- Emissions level
- Locating EMI sources in PCBs
- Locating EMI sources in ICs
- Human exposure of EMF

Far Field and Near Field: Fundamentals



Far Field: Plane wave

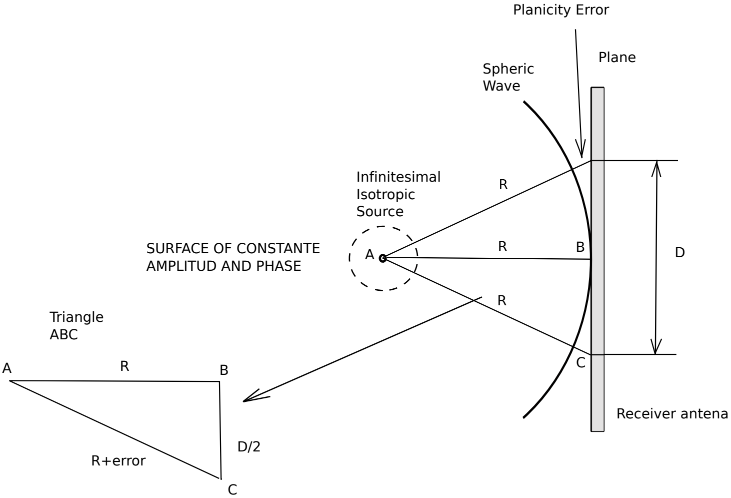
$\vec{E}$, $\vec{H}$ and $\vec{P}$ are ortogonals



Near Field: Sphericall wave produced near a dipole antenna

Far Field and Near Field Fundamentals: Isotropic Point Source

Illustration of an isotropic point source, with the sphericall and plane waves

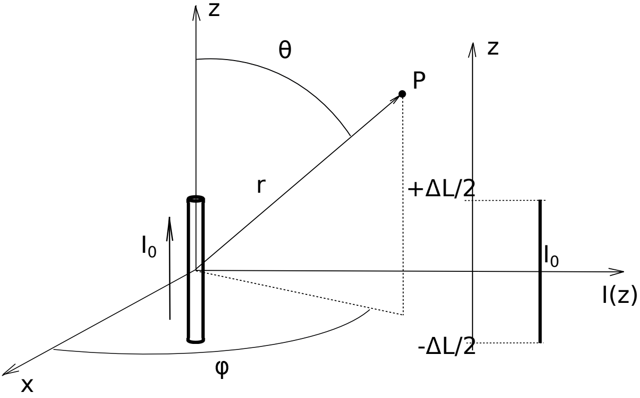


Far Field and Near Field Fundamentals: Isotropic Point Source

The spherical electromagnetic wave it's radiated from a point source.
The error between the plane and the Sphere is $\lambda/16$ or $\pi/8$ radians
Then the distance for the far field is:

$$\boxed{R \cong \frac{2D^2}{\lambda}} \tag{1}$$

Illustration of an Ideal Dipole, and the current distribution. $\Delta L << \lambda$ and $I(a, \theta, \phi) = I_0$



Ideal Dipole Antenna

Ideal Electric Dipole

Electric and magnetic fields of an infinitesimal dipole

$$E_\theta = \frac{I_0 e^{-j\beta r} \Delta L sin\theta}{4\pi} \left(\frac{j\omega\mu}{r} + \frac{Z_{00}}{r^2} + \frac{1}{j\omega\epsilon r^3} \right) \tag{2}$$

$$E_r = \frac{I_0 e^{-j\beta r} \Delta L cos\theta}{4\pi} \left(\frac{Z_{00}}{r^2} + \frac{1}{j\omega\epsilon r^3} \right) \tag{3}$$

$$H_\phi = \frac{I_0 e^{-j\beta r} \Delta L sin\theta}{4\pi r} \left(j\beta + \frac{1}{r} \right) \tag{4}$$

(5)

Ideal Electric Dipole

Wave impedance of an Ideal Dipole

$$Z_1 = \frac{E_\theta}{H_\phi} = \frac{\left(\frac{j\omega\mu}{r} + \frac{Z_{00}}{r^2} + \frac{1}{j\omega\epsilon r^3}\right)}{\left(\frac{j\beta}{r} + \frac{1}{r^2}\right)} \tag{6}$$

$$Z_2 = \frac{E_r}{H_\phi} = \frac{cos\theta}{sin\theta} \frac{\left(\frac{Z_{00}}{r^2} + \frac{1}{j\omega\epsilon r^3}\right)}{\left(\frac{j\beta}{r} + \frac{1}{r^2}\right)} \tag{7}$$

Far Field

- The E and H fields are mutually perpendicular to that direction.
- The ratio of E and H is 377 with cero degree of phase.
- There is no unique distance beyond which the far field exists.
- The equations can be aproximated to $1/r$.

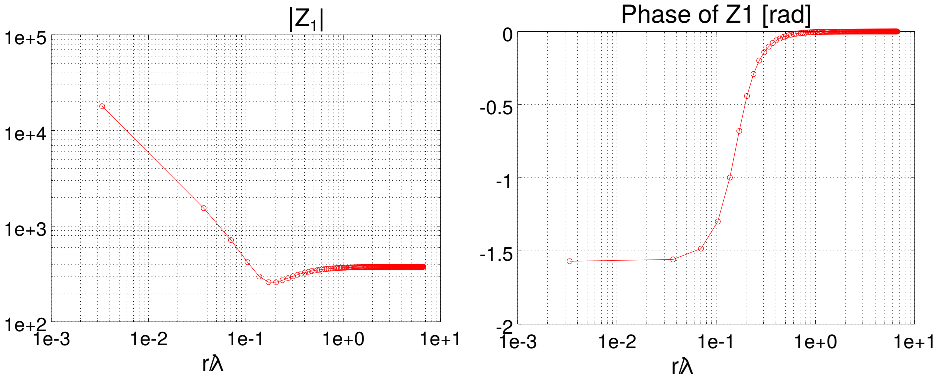
Ideal Electric Dipole

Near Field

- The equations that describe E and H fields vary radially and angularly with respect to an RF source.
- The ratio of E and H is diferent to 377Ω.
- Field equations include $1/r$, $1/r^2$, and $1/r^3$ terms.
- Small fractional values of r cause the $1/r^3$ term to become large. Conversely, for large values of r, the 1/r term may be orders of magnitude bigger than the others.
- Three regions can be defined: the reactive near field, the radiating near field, and the far field.

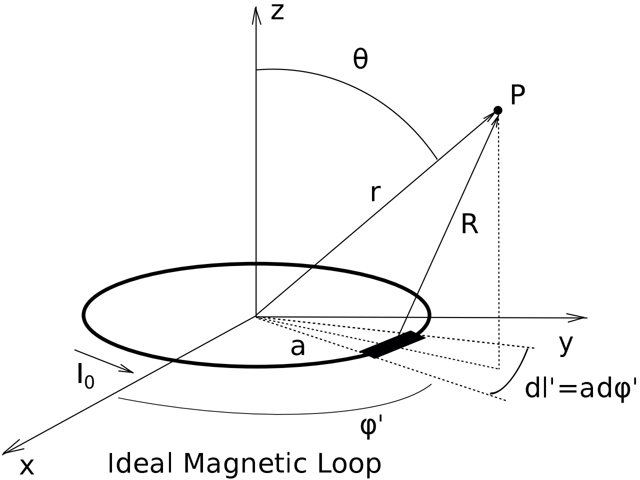
Ideal Electric Dipole

Wave impedance Z_1 as a function of r/λ



Ideal Magnetic dipole

Illustration of an Ideal Magnetic Dipole and the current distribution.
$C = 2\pi aN << \lambda$ and $I(a, \theta, \phi) = I_0$



Ideal Magnetic Loop

Electric and magnetic fields of an Ideal Magnetic dipole

$$E_{\phi} = \frac{I_0 e^{-j\beta r} Z_{00} (\beta a)^2 sin\theta}{4r} \left(1 + \frac{1}{j\beta r}\right) \quad (8)$$

$$H_r = \frac{I_0 a^2 (j\beta) e^{-j\beta r} cos\theta}{2r^2} \left(1 + \frac{1}{j\beta r}\right) \quad (9)$$

$$H_{\theta} = \frac{I_0 (\beta a)^2 e^{-j\beta r} sin\theta}{4r} \left(1 + \frac{1}{j\beta r} - \frac{1}{(\beta r)^2}\right) \quad (10)$$

$$(11)$$

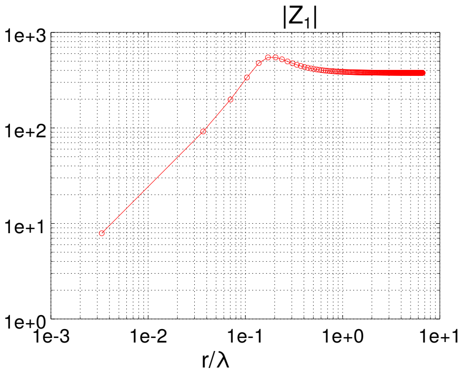
Ideal Magnetic dipole

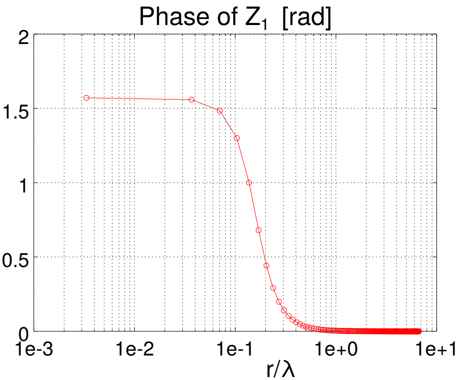
Wave impedance of an Ideal Magnetic dipole

$$Z_1 = \frac{E_\phi}{H_\theta} = Z_{00} \frac{\left(1 + \frac{1}{j\beta r}\right)}{\left(1 + \frac{1}{j\beta r} - \frac{1}{(\beta r)^2}\right)} \tag{12}$$

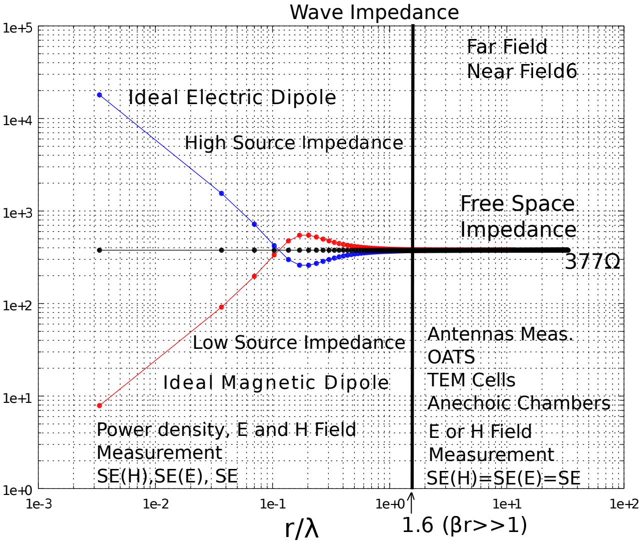
$$Z_2 = \frac{E_\phi}{H_r} = \frac{Z_{00}}{2j} \frac{sin\theta}{cos\theta} \frac{\left(1 + \frac{1}{j\beta r}\right)}{\left(\frac{1}{\beta r} + \frac{1}{j(\beta r)^2}\right)} \tag{13}$$

Wave impedance Z_1 as a function of r/λ

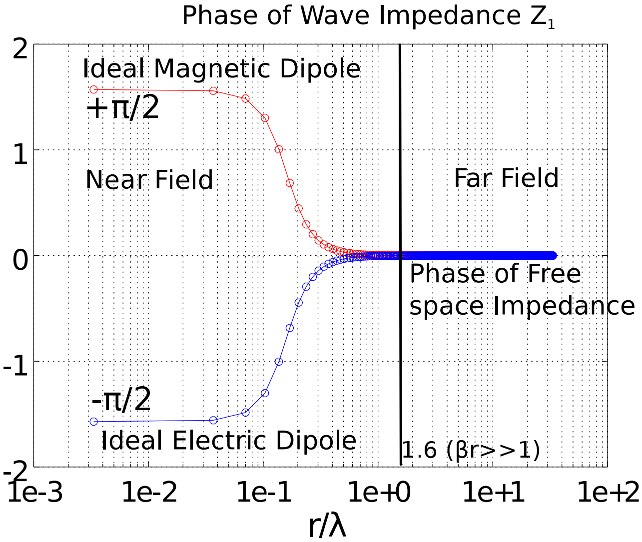




Wave Impedance $|Z_1|$ as a function of r/λ



Wave Impedance Phase of Z_1 as a function of r/λ



Ideal Magnetic and Electric Dipole

Fields as a function of the distance:

$$E(\alpha) = C_1(\alpha)\frac{e^{-j\beta R}}{R^\alpha} \qquad \texttt{Ideal Electric Dipole} \tag{14}$$

$$H(\alpha) = C_2(\alpha)\frac{e^{-j\beta R}}{R^\alpha} \qquad \texttt{Ideal Magnetic Dipole} \tag{15}$$

where:

$3 \leq \alpha \leq 0$

$0 < R < \infty$

$\alpha = 3$ Near Field

$\alpha = 2$ Intermediate Field

$\alpha = 1$ Far Field

Finite Length Electric Dipole

Fields as a function of the distance:

$$E(\alpha) = C_1(\alpha)\frac{e^{-j\beta R}}{R^{\alpha}} \tag{16}$$

$$H(\alpha) = C_2(\alpha)\frac{e^{-j\beta R}}{R^{\alpha}} \tag{17}$$

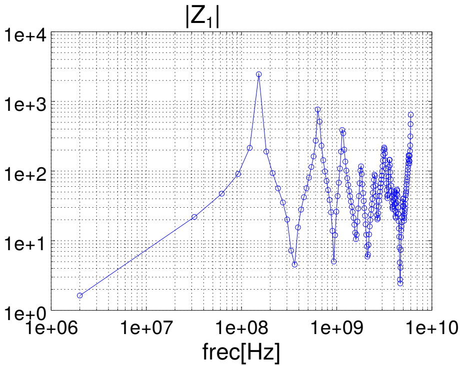
where:

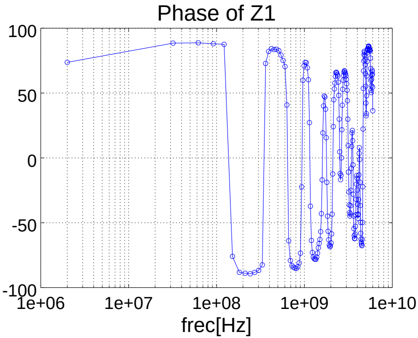
$0 < R < \infty$

$0 < \alpha < 1$

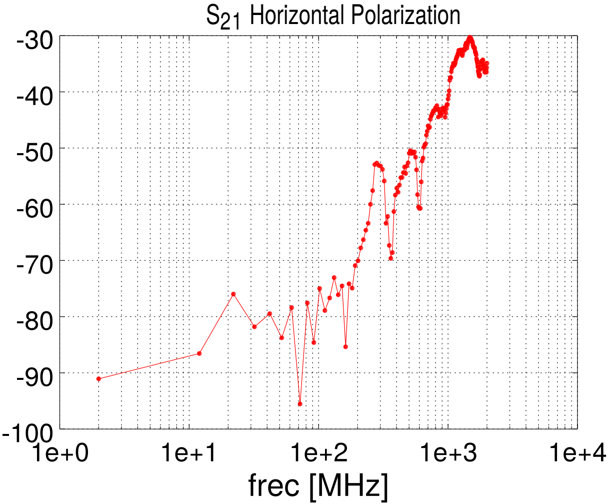
Loop antenna: 1turn and N connector

Z of a Loop antenna 1turn and N connector

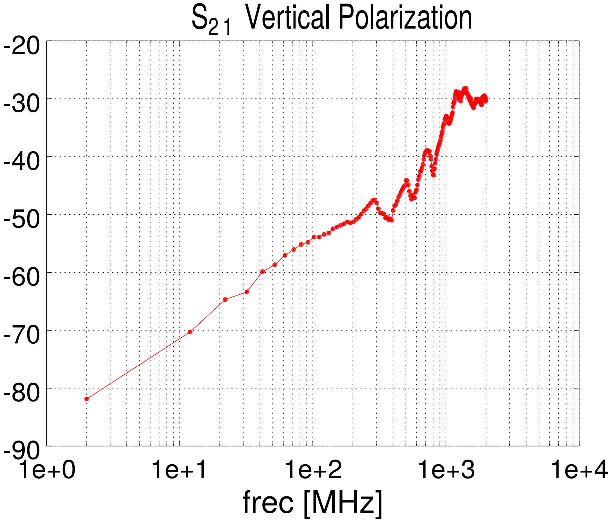




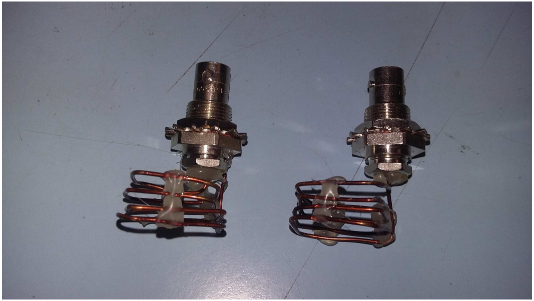
$|S21|$ Loop air core. N=1 turn. PH



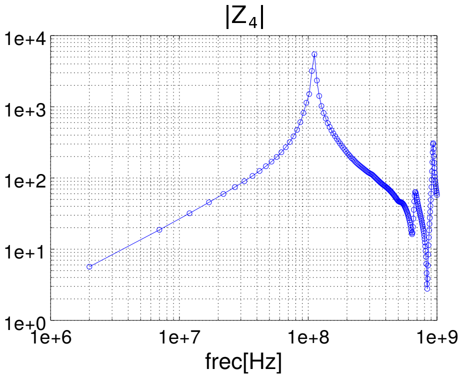
$| S_{21} |$ Loop air core. N=1 turn. PV



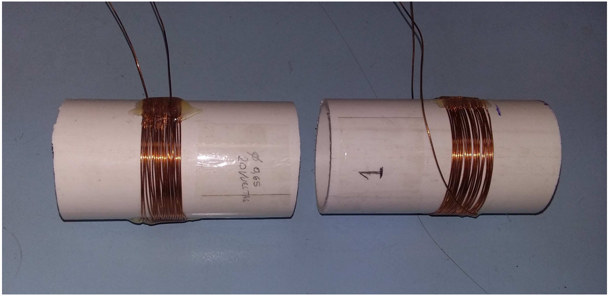
Loop antenna: 4turns, BNC connector



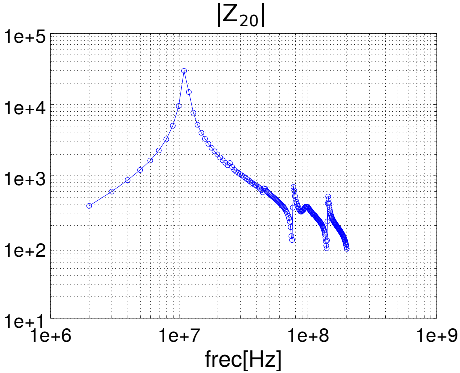
Z of a Loop antenna 4turns, BNC connector

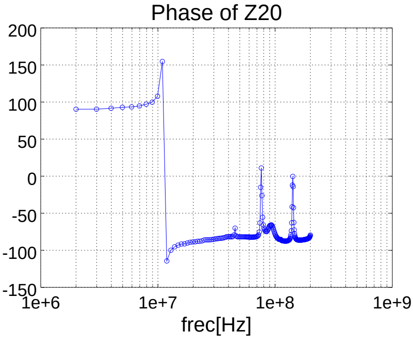


Loop antenna
20 turns
$L = 26\mu H$
$R = 0.28\Omega \ (f = 100kHz)$
$Q = 61 \ (f = 100kHz)$



Z of a 20turns, N connector





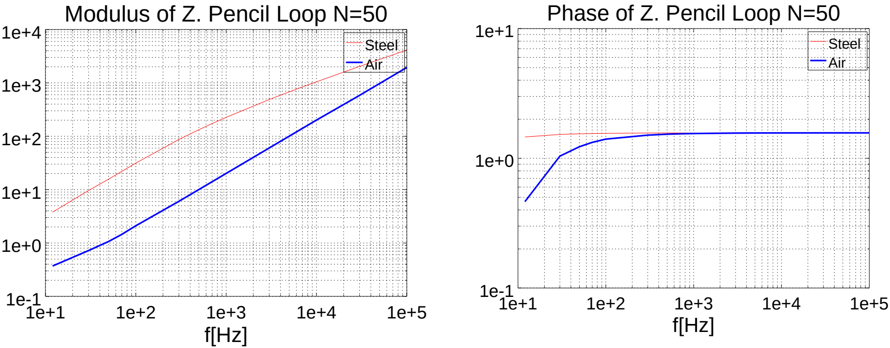
Pencil Loop with steel core.

50 turns

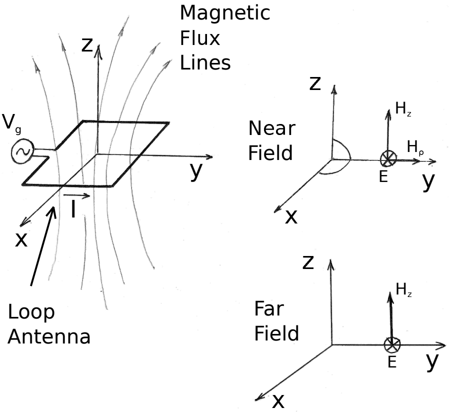
$\phi_{core} = 4mm$ diameter of the core

$\phi_{wire} = 0.3mm$ diameter of the wire

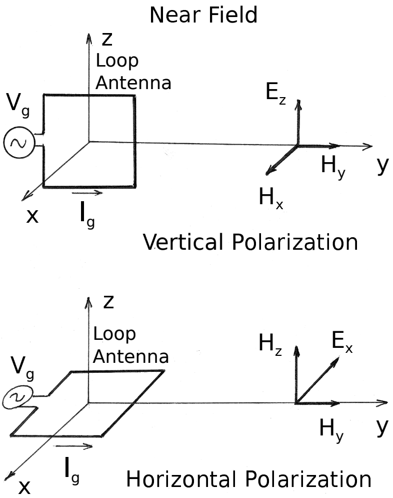
Pencil Loop with steel and air core.



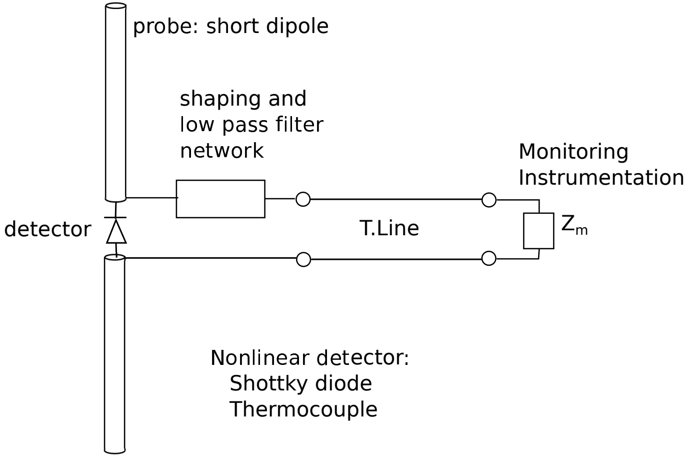
H Field Probes



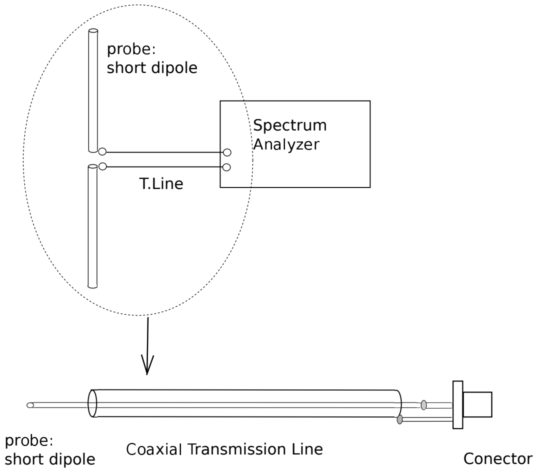
H Field Probes



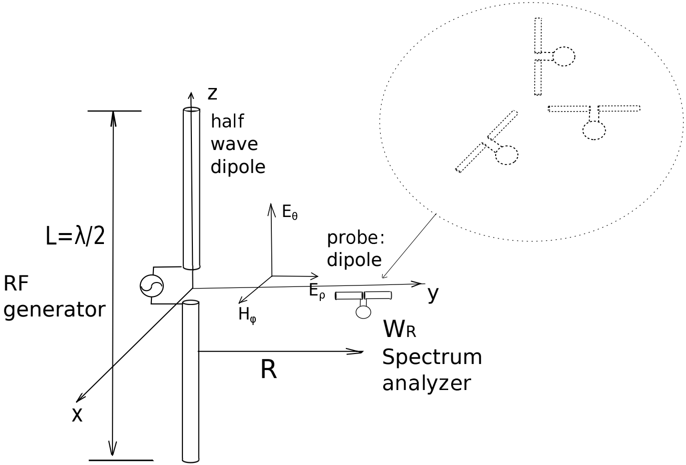
Electric Field Probe circuit

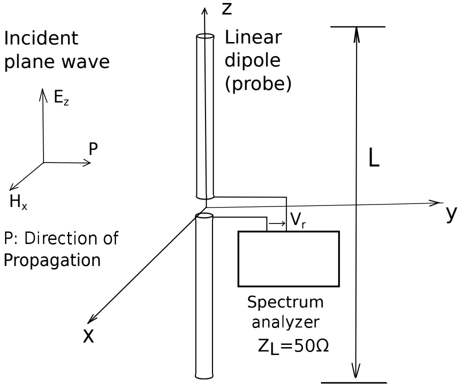


Simple Electric Field Probe circuit



Measurement E Field components E_x, E_y and E_z





Effective Length of a Linear Antenna

$$V_r = E_{inc} L_{eff} \tag{18}$$

where V_r is measured by spectrum analyzer

Half Wave Dipole Measurement

The received Voltage measured by the spectrum analyzer:

$$V_r = \sqrt{W_r Z_L} \tag{19}$$

And

$$V_{oc} = V_r \left(\frac{Z_{in} + 50\Omega}{50\Omega} \right) \tag{20}$$

The effective length of a dipole is the relation between Received Voltage and Electric Field incident to the probe:

$$E_{inc} = \frac{V_{oc}}{L_{eff}} \tag{21}$$

where L_{eff} for thin linear antennas (probe) is:

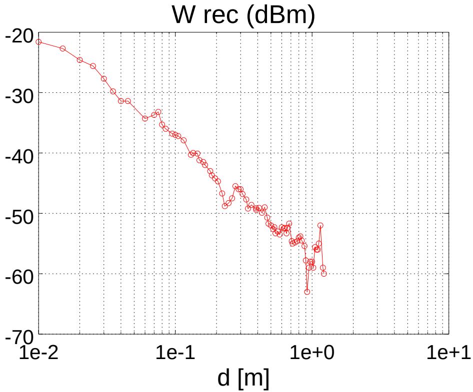
$$\frac{L_{eff}}{\lambda} = \frac{1}{\pi} \left(\frac{1 - cos(\frac{\pi L}{\lambda})}{sin(\frac{\pi L}{\lambda})} \right) \tag{22}$$

Electric Field incident to the probe (probe: thin dipole antenna)

$$\boxed{E_{inc} = \frac{\sqrt{W_r Z_L}}{\frac{\lambda}{\pi}\left(\frac{1-cos(\frac{\pi L}{\lambda})}{sin(\frac{\pi L}{\lambda})}\right)}\left(\frac{Z_{in}+50\Omega}{50\Omega}\right)} \tag{23}$$

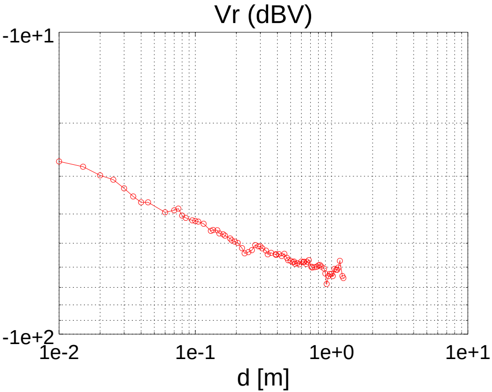
Where:
$L(m)$ is the length of the dipole (probe)
$Z_L = 50\Omega$ is the impedance of spectrum analyzer
$W_r(W)$ is the power measured by the spectrum analyzer
$E(V/m)$: is the electric field incident to the Probe
Z_{in}: is the input impedance of the antenna.

Power Measured with a short dipole Probe: $L = 0.48\lambda$ $(30mm)$

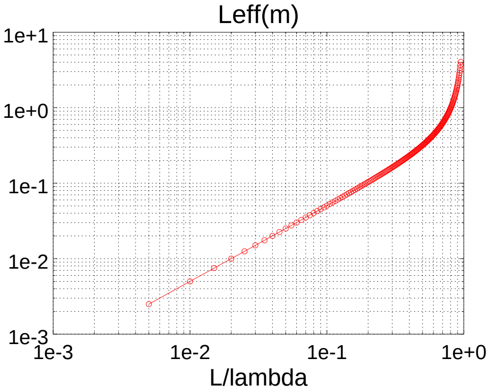


Half Wave Dipole Measurement

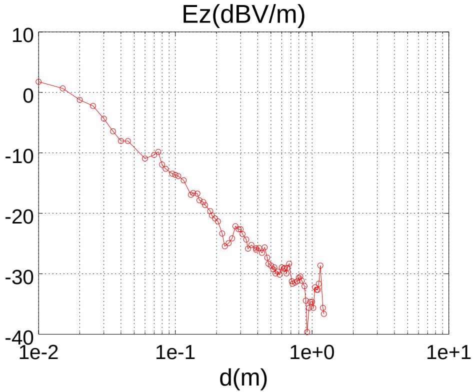
Voltage Measured with a short dipole Probe: $L = 0.48\lambda$ $(30mm)$



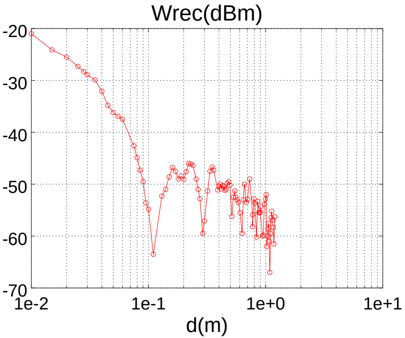
Effective length of the probe (short dipole) Probe: $L = 0.48\lambda$ ($30mm$)

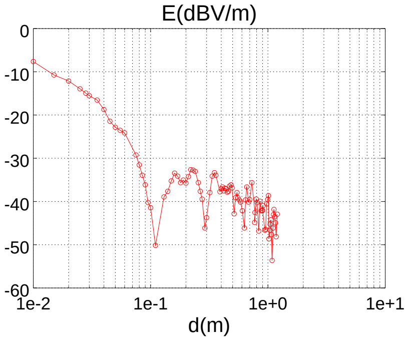


Electric Field measured with the probe (short dipole) Probe:$L = 0.48\lambda$ ($30mm$)

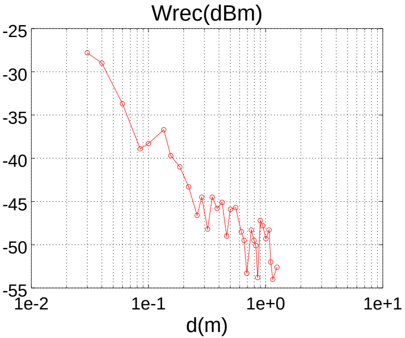


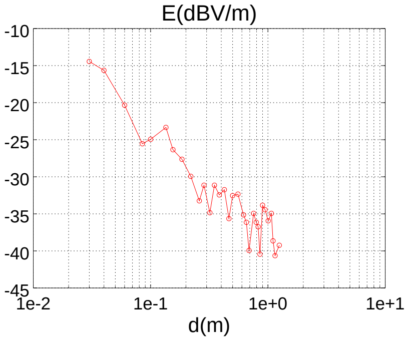
Electric Field measured E_ρ with the probe (short dipole) Probe:$L = 0.48\lambda$ $(30mm)$



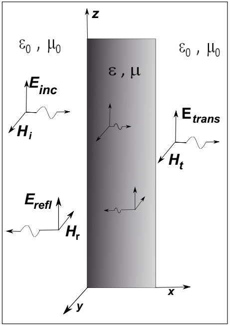


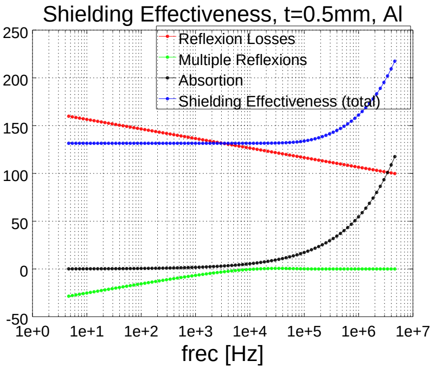
Electric Field measured E_ϕ with the probe (short dipole) Probe:$L = 0.48\lambda$ $(30mm)$





Shielding effectiveness measurement of a slab material





S.A. Schelkunoff "Electromagnetic Waves", Van Nostran Company.

Traditional Theory of Shielding with Plane Waves on a slab.

Shielding effectiveness measurement of a slab material

Definition (E):

$$\boxed{SE(dB) = 20\log\left(\frac{E_i}{E_t}\right)} \tag{24}$$

Definition (H):

$$\boxed{SE(dB) = 20\log\left(\frac{H_i}{H_t}\right)} \tag{25}$$

$$SE(dB) = R(dB) + A(dB) + M(db) \tag{26}$$

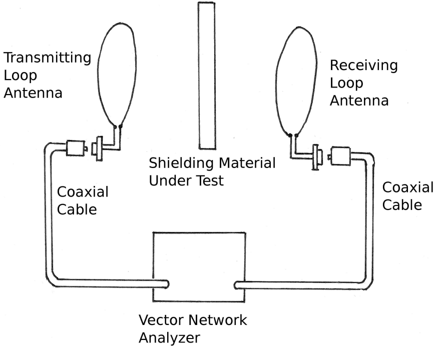
$R(dB) = 20log\left|\frac{(Z_0+Z)^2}{4Z_0Z}\right|$

$M(dB) = 20log\left|1-\left(\frac{Z_0-Z}{Z_0+Z}\right)^2 e^{-2t/\delta}e^{-2j\beta t}\right|$

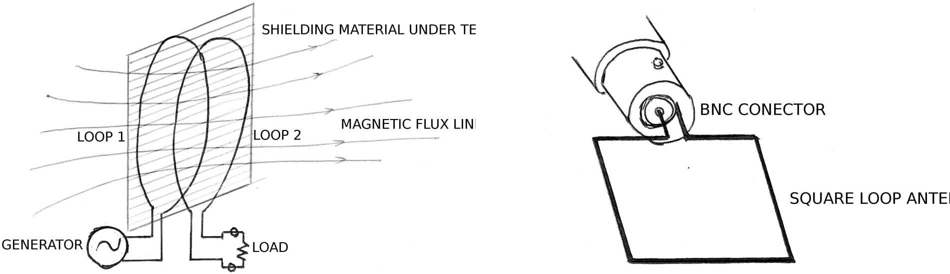
$A(dB) = 20log\left(e^{t/\delta}\right)$

Shielding effectiveness measurement at Low frequencies

Setup of Shielding effectiveness measurement, using two Loops antennas for Radio-frequencies connected to the Vector Network Analyzer (VNA)



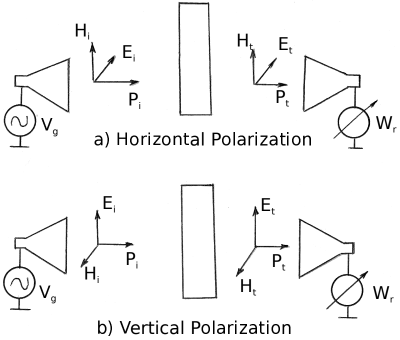
Shielding effectiveness measurement at Low frequencies



a) Setup of Shielding effectiveness measurement with two Loops antennas for Radio-frequencies. b) Loop antenna schematic.

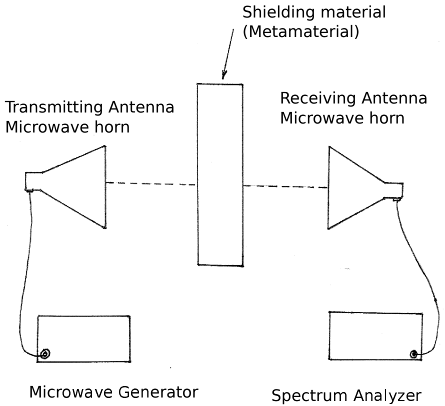
Shielding effectiveness measurement at High Frequencies

Setup of Shielding effectiveness measurement, using two horns antennas for microwaves frequencies for two polarization modes: Parallel and Perpendicular.



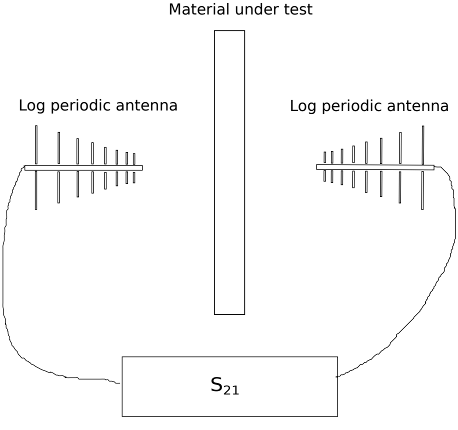
Shielding effectiveness measurement at High Frequencies

Setup of Shielding effectiveness measurement, using two horns antennas for microwaves frequencies

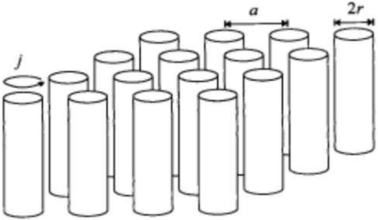


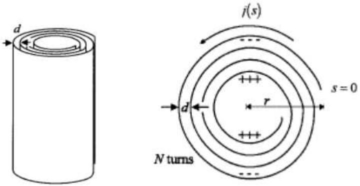
Shielding effectiveness measurement at High Frequencies

Setup of Shielding effectiveness measurement, using two Log Periodic antennas for two different ranges: 500-900MHz and 900-3000MHz, for Vertical and Horizontal Polarization.



Wide Scren Metamaterial as Shielding





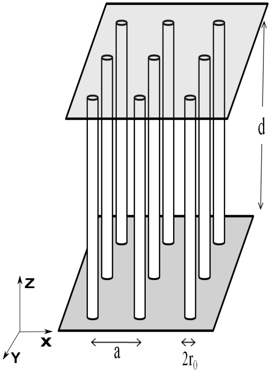
Antennas used for measurements (a) 400-900 MHz. (b) 900-4000 MHz.

(a)

(b)

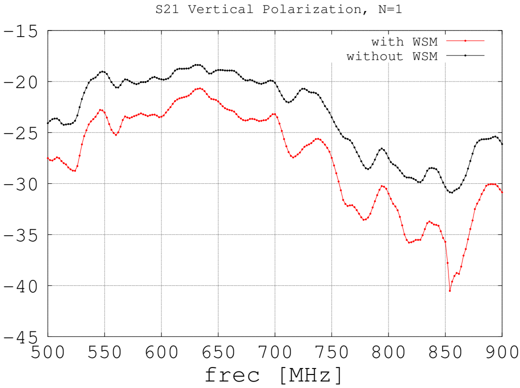
Shielding effectiveness measurement

Wide Screen Metamaterial $a = 20mm$, $2r_0 = 4mm$,



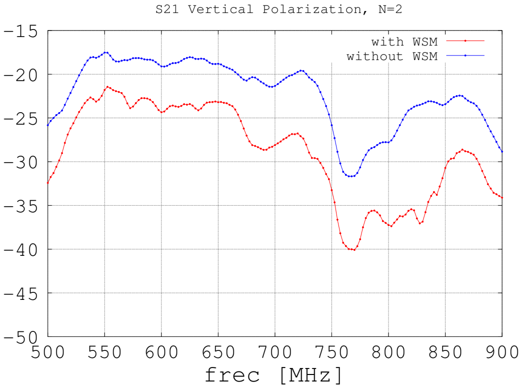
Shielding effectiveness measurement at High Frequencies

Vertical Polarization N=1. Log-Periodic Antenna.



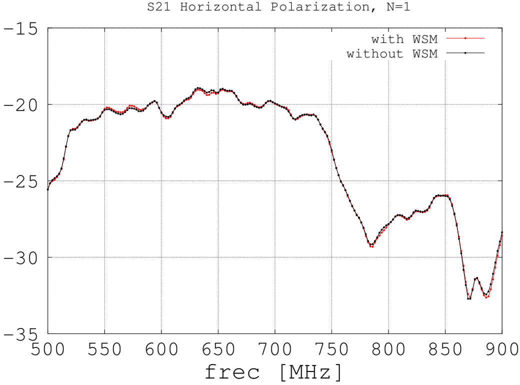
Shielding effectiveness measurement at High Frequencies

Vertical Polarization N=2. Log-Periodic Antenna.



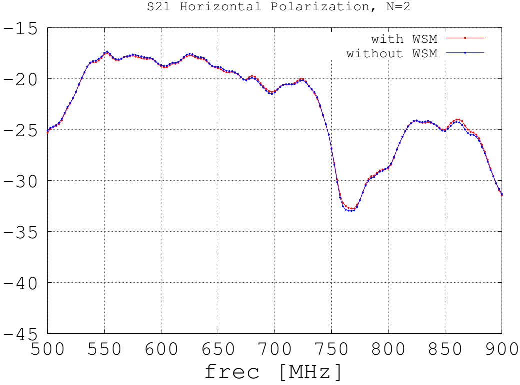
Shielding effectiveness measurement at High Frequencies

Horizontal Polarization N=1. Log-Periodic Antenna.



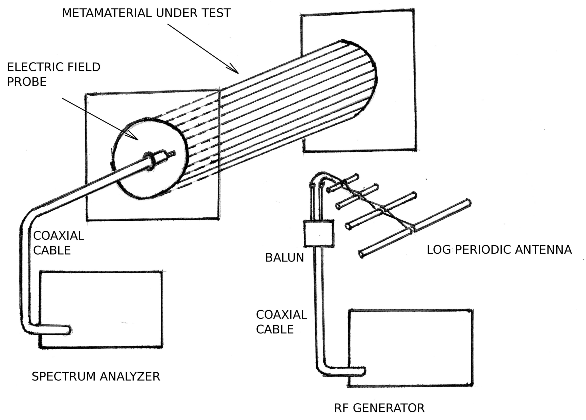
Shielding effectiveness measurement at High Frequencies

Horizontal Polarization N=2. Log-Periodic Antenna.



Shielding effectiveness measurement setup

This setup will be developed soon by Sivina Boggi and Ramiro Alonso



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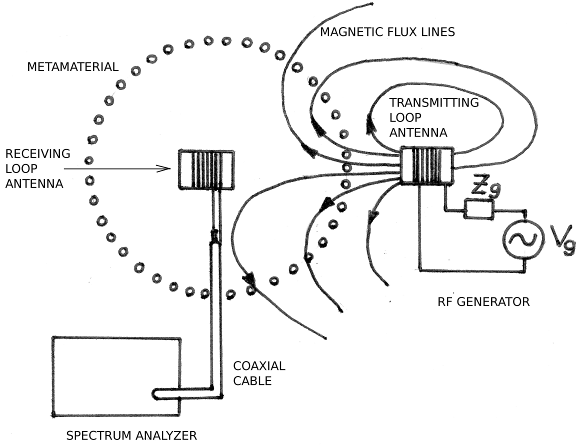
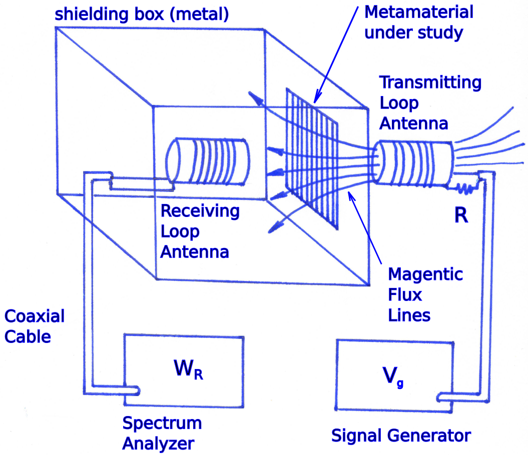
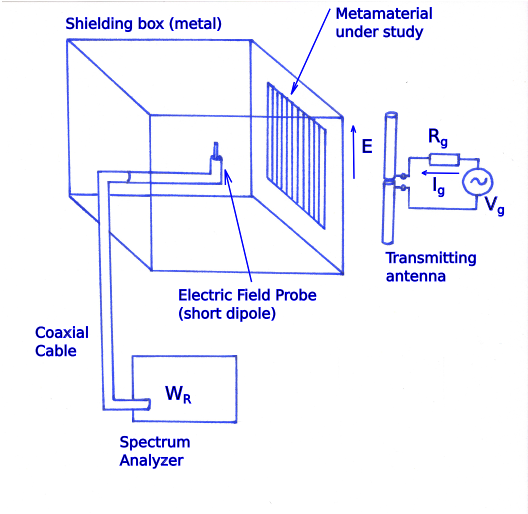
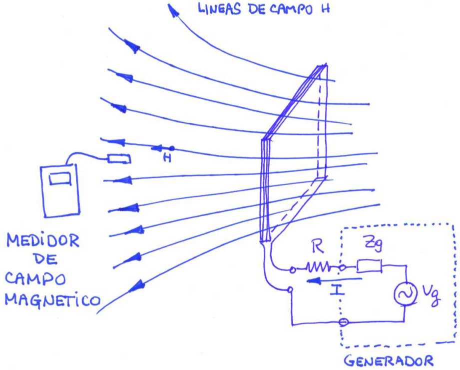



shielding box (metal)
Metamaterial under study
Transmitting Loop Antenna
Receiving Loop Antenna
R
Magentic Flux Lines
Coaxial Cable
W_R
V_g
Spectrum Analyzer
Signal Generator

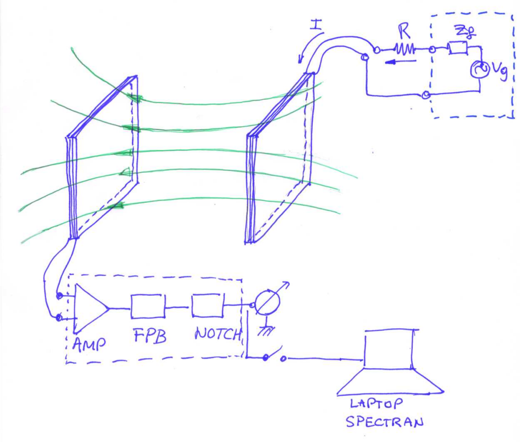
Shielding effectiveness measurement



Curva de Calibracion del campo magnÍtico vs Vmedida



Curva de Calibracion del campo magnt́ico vs Vmedida



Curva de Calibracion del campo magntíco vs Vmedida

El Factor de corrección o K relaciona H incidente a la antena con la tensión en los terminales de la antena (V):

$$H = VK \tag{27}$$

Donde K $K[\frac{A}{Vm}]$.

Curva de Calibracion del campo magntíco vs Vmedida

La tension inducida en un inductores:

$$\oint_{c} \overrightarrow{E} \cdot \overrightarrow{dl} = -N \oint_{S} \frac{\partial \overrightarrow{B}}{\partial t} \cdot \overrightarrow{dS} \tag{28}$$

si λ es mucho menor que las dimensiones de la antena [**?**]:

$$V_{induced} = -N \frac{\partial B(t)}{\partial t} A = \omega \mu HAN \tag{29}$$

donde A es el area del núcleo

Curva de Calibracion del campo magnético vs Vmedida

$$V_{out} = G_{Probe} V_{induced} \tag{30}$$

Then:

$$V_{out} = G_{Probe} \omega \mu H A N \tag{31}$$

The correction factor is:

$$K[\frac{A}{mV}] = \frac{1}{G_{Probe} \omega \mu A N} \tag{32}$$

Thanks for your attention.

Any Question?