Antennas in UWB Systems[1]

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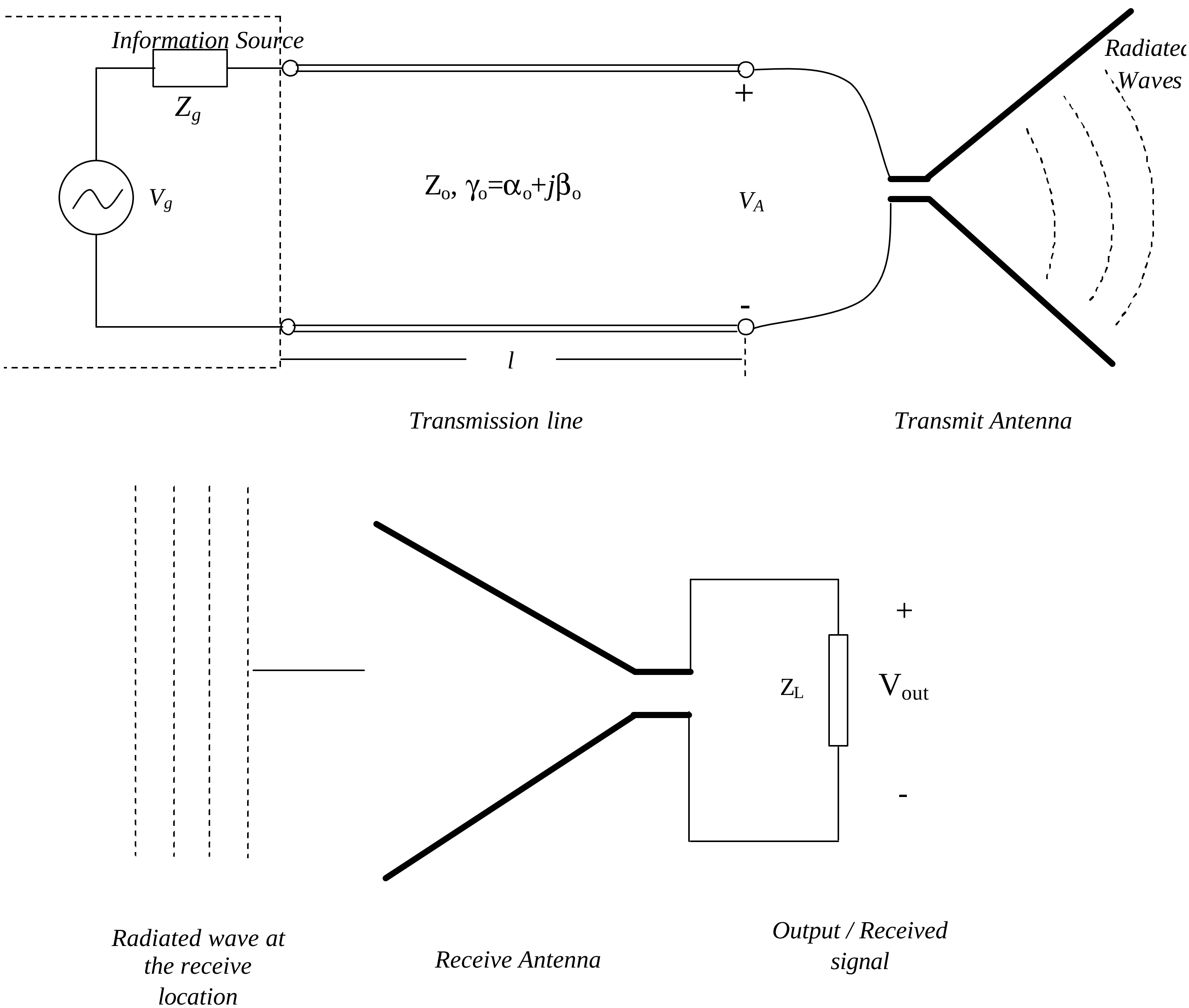
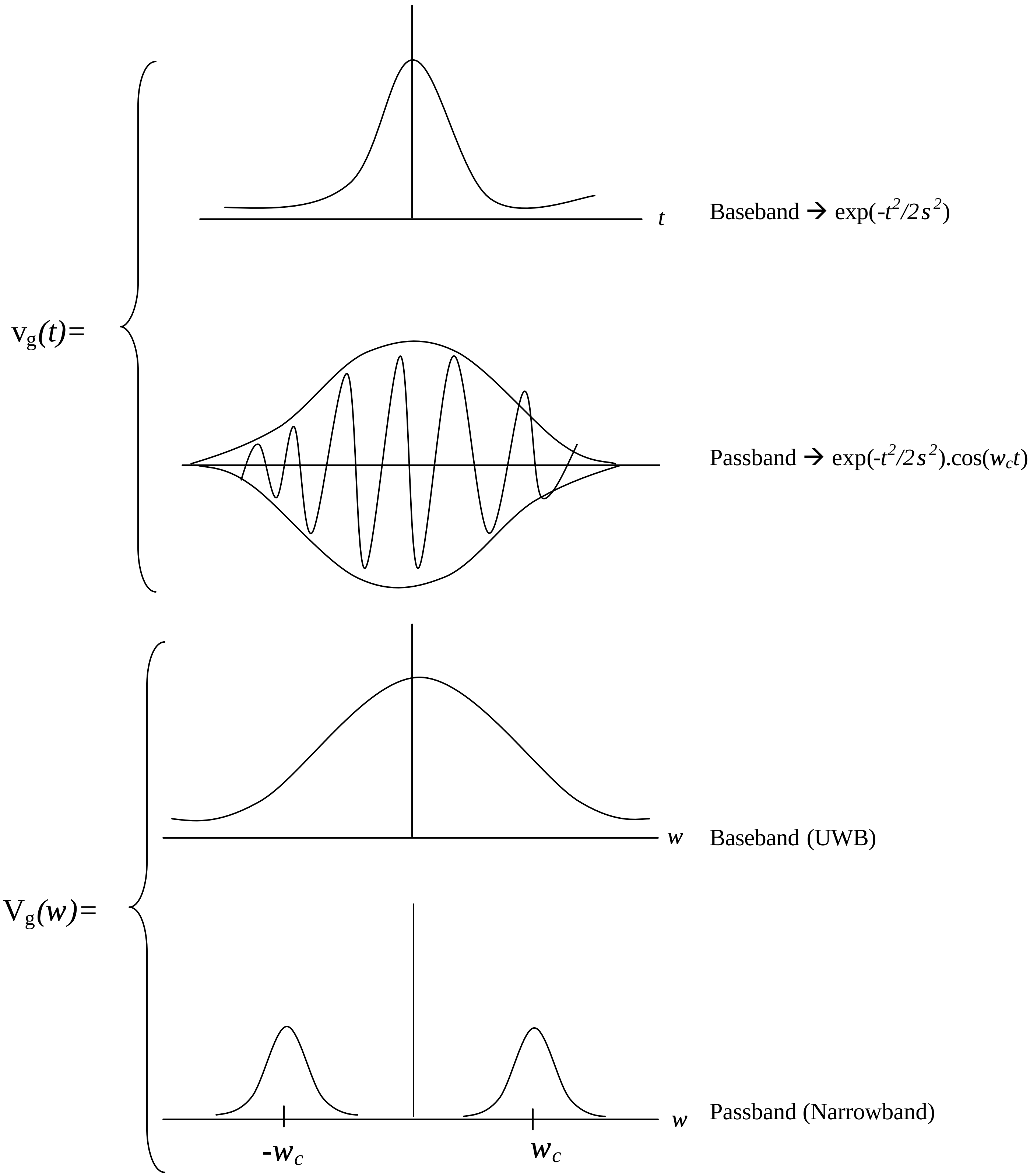
Objectives:

(a) Follow the signal through the following stages and see what happens to it,
- Information Source → Transmission Line
- Transmission Line → Transmit Antenna
- Examine the radiated field and investigate its relationship to the information signal.
- Examine the received signal.
- Address signal distortion due to antenna input impedance, radiation pattern (gain), and polarization.

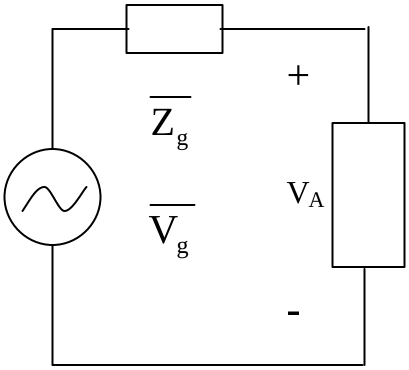
(b) Examine the passband (narrowband) and baseband (wideband) cases.
(c) Investigate desired characteristics of antennas for UWB applications.



Information Source
Zg
Vg
Zo, γo=αo+jβo
+
VA
-
l
Radiated
Waves
Transmission line
Transmit Antenna
+
ZL
Vout
-
Radiated wave at the receive location
Receive Antenna
Output / Received signal



$v_g(t)$=
t
Baseband → $\exp(-t^2/2s^2)$
Passband → $\exp(-t^2/2s^2).\cos(w_c t)$
$V_g(w)$=
w
Baseband (UWB)
w
Passband (Narrowband)
$-w_c$
w_c



Z_A=R_A+jX_A. Z_A is antenna input impedance.

$$\overline{V_g} = V_g \frac{Z_o}{Z_o \cosh(g_o l) + Z_g \sinh(g_o l)}$$

$$\overline{Z_g} = Z_o \frac{Z_g + Z_o \tanh(g_o l)}{Z_o + Z_g \tanh(g_o l)}$$

When Z_g=Z_o, transmission line is matched to the generator, and

$$\overline{V_g} = V_g . e^{-g_o l} = V_g . e^{-a_o l} e^{-jb_o l}$$

$$\overline{Z_g} = Z_o$$

$$V_A = \overline{V_g} \frac{Z_A}{Z_A + \overline{Z_g}}$$

In practical situations, Z_g, Z_o, and $\overline{Z_g}$ =Z_o are real, but Z_A may have a substantial imaginary part.

Implications ?

(i) Less than maximum possible power delivered to the antenna.
(ii) Significant signal distortion may occur to wideband signals.

Remedy →

- For narrowband applications, the use of a matching network solves the problem.
- For wideband and UWB applications, ideally a wideband antenna with $Z_A=Z_o$ should be used, or a wideband matching network is needed.
- If an antenna, intended for UWB applications, has a real input impedance ($X_A \cong 0$), the transmission line and the generator might be designed such that $Z_g=Z_0=R_A$. 50Ω or 75Ω cables may not be a satisfactory choice for UWB application!

Assuming that $Z_A=\overline{Z_g}=Z_0$, then

$$V_A = \frac{1}{2} V_g e^{-a_o l} e^{-jb_o l}$$

$$v_A(t) = \frac{1}{2} v_g e^{-a_o l}\left(t - \frac{l}{v_o}\right), \quad v_o = \frac{w}{b_o}$$

- Antenna input voltage $v_A(t)$ results in an input current $i_A(t)=v_A(t)/Z_o$ which in turn, establishes a current distribution $\vec{J}(x, y, z; t)$ on the antenna structure.
- The current distribution $\vec{J}$ gives rise to electromagnetic fields $\vec{E}$ and $\vec{H}$ which are governed by Maxwell's equations.

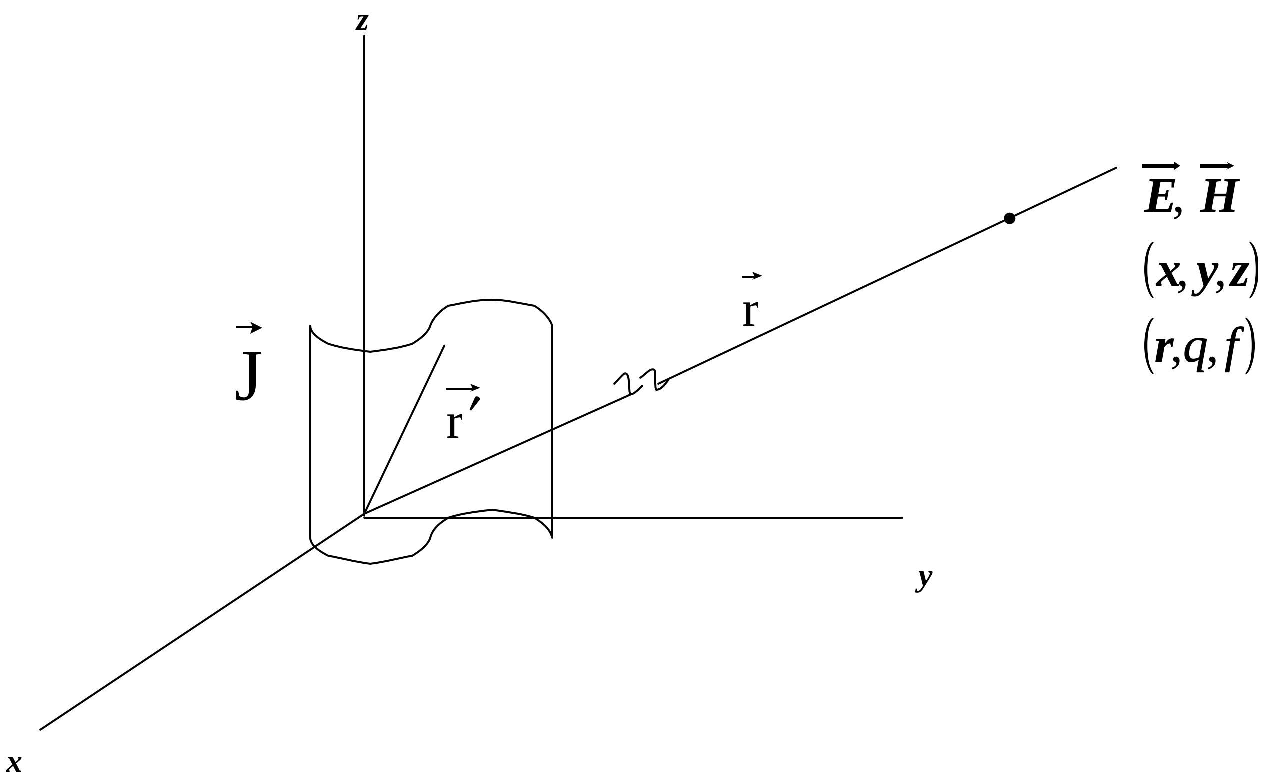
$$\nabla \mathrm{X} \vec{E} = -m \frac{\partial \vec{H}}{\partial t}$$

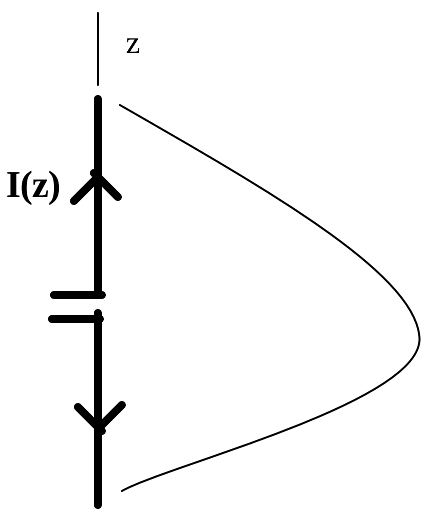
$$\nabla \mathrm{X} \vec{H} = \vec{J} + e \frac{\partial \vec{E}}{\partial t}$$

$$\nabla \bullet \vec{E} = r/e$$

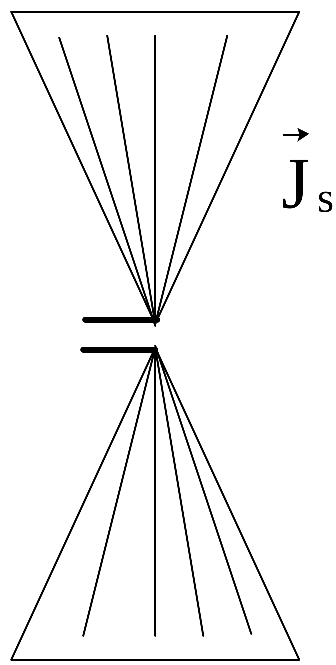
$$\nabla \bullet \vec{H} = 0$$

- Solutions for $\vec{E}$ and $\vec{H}$?
  - Time-Domain Approach → FDTD (Finite difference time domain)
  - Frequency-Domain Approach





Filamentary current



Surface current

Time-Domain Response:

If $i_A(t)=f(t)$, where $f(t)$ is an arbitrary function of time whose Fourier transform $F(\omega)$ exists, then the resulting radiated field is obtained from:

$$i_A(t) = \cos(\omega t) = \mathrm{Re}\{e^{j\omega t}\}$$

$$\nabla X\vec{E} = -j\omega\mu\vec{H}$$

$$\nabla X\vec{H} = \vec{J} + j\omega\varepsilon\vec{E}$$

Far-filed solutions for $\vec{E}$ and $\vec{H}$:

$$\vec{E}(\vec{r}) = \vec{E}(x, y, z) = -jwm\frac{e^{-jbr}}{4pr}\underbrace{\left[P_q(q, j, w)\hat{q} + P_j(q, j, w)\hat{j}\right]}_{\vec{P}_1(\theta,\varphi,\omega)}$$

where

$$\vec{P}_1(q, j, w) = \vec{P}(q, j, w) - P_r(q, j, w)\hat{r}$$

$$\vec{P}(q, j, w) = \int_{v'} \vec{J}(\vec{r}')e^{jb\vec{r}'\bullet\hat{r}}dv' \qquad \text{Volume current}$$

$$= \int_{s'} \vec{J}_s(\vec{r}')e^{j\beta\vec{r}'\bullet\hat{r}}ds' \qquad \text{Surface current}$$

$$= \int_{C'} I(\vec{r}')e^{j\beta\vec{r}'\bullet\hat{r}}d\vec{l}' \qquad \text{Filamentary current}$$

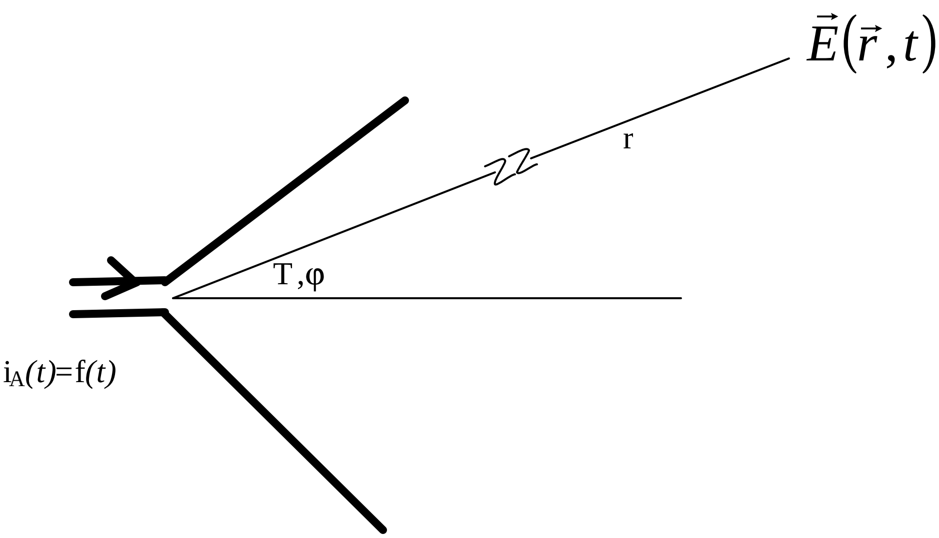
$$\vec{E}(\vec{r},t) = -\frac{m}{4pr}\int_{-\infty}^{\infty}\frac{1}{2p}\, jw\underbrace{F(w)\vec{P}_1(q,j,w)}_{=\vec{G}(q,j,w)}e^{j\left(t-r/v\right)w}\,dw$$

where

$F(w) = \Im\{f(t)\}$ and $v = \frac{1}{\sqrt{me}} = \frac{w}{b}$

Therefore,

$$\vec{E}(\vec{r},t) = -\frac{m}{4pr}\frac{d}{dt}\left[\vec{g}\left(q,j;t-r/v\right)\right]$$



$$\vec{H} = \frac{1}{h}\hat{r}X\vec{E}$$

Example:

Antenna: Dipole of length L

Signal: $f(t) = e^{-t^2/2s^2}$

$$\vec{P}_1(q,j,w) = \frac{v}{w}\frac{\cos\left(\frac{wL}{2v}\right) - \cos\left[\frac{wL}{2v}\cos q\right]}{\sin q}\hat{q}$$

where v = $3\text{x}10^8$ m/sec,
L = 1 m,
σ = 1 µsec, 0.1µsec, 0.01µsec.

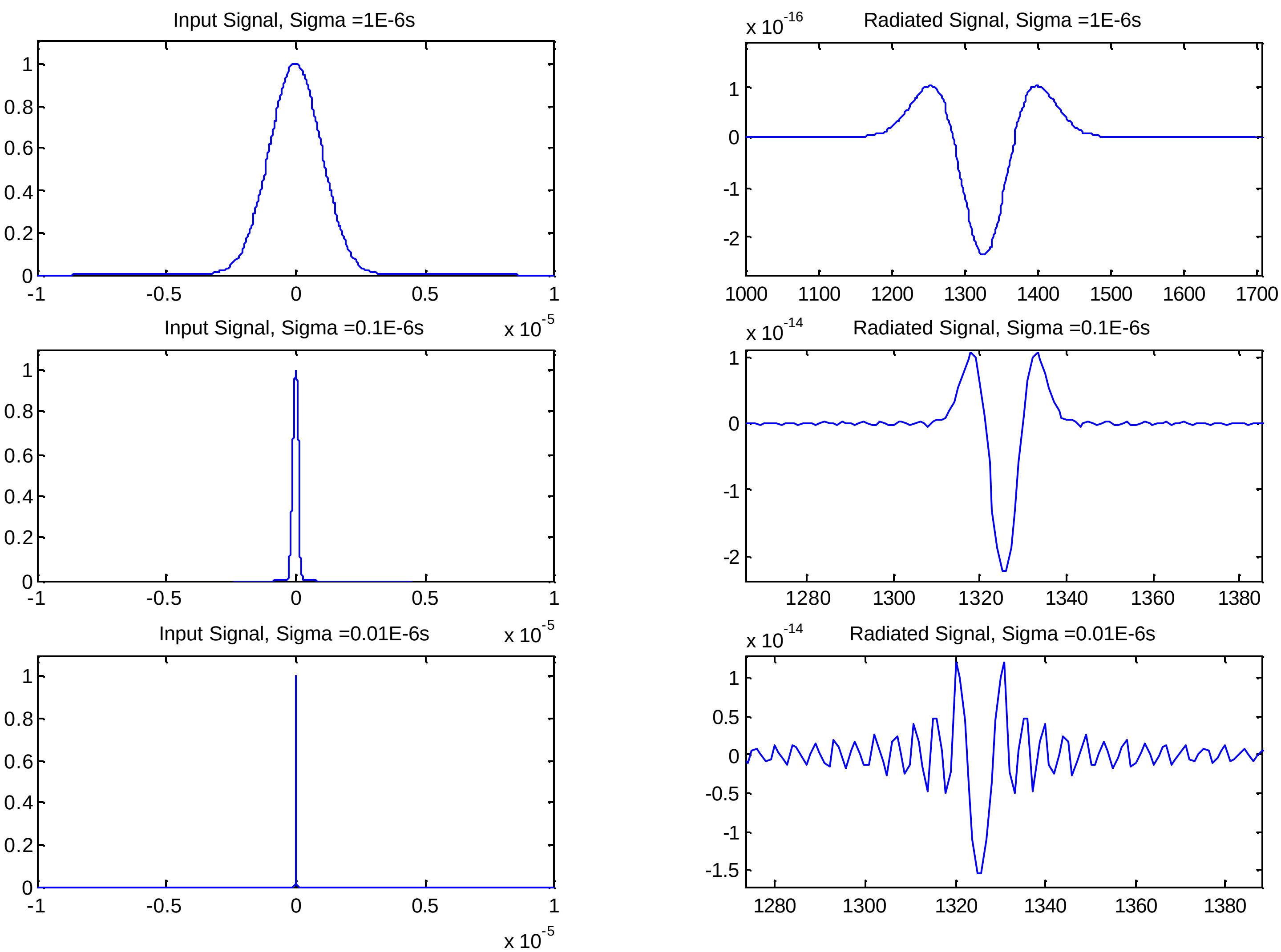
For σ = 1 µsec and 0.1µsec, the dipole is short compared to all wavelengths in the signal bandwidth. Thus, $\frac{wL}{2v} << 1$:

$$\vec{P}_1(q,j,w) \cong \frac{1}{2}\frac{v}{w}\left(\frac{wL}{2v}\right)^2 \sin q\ \hat{q} = \frac{1}{2}v\left(\frac{L}{2v}\right)^2 \sin q\ w\ \hat{q}$$

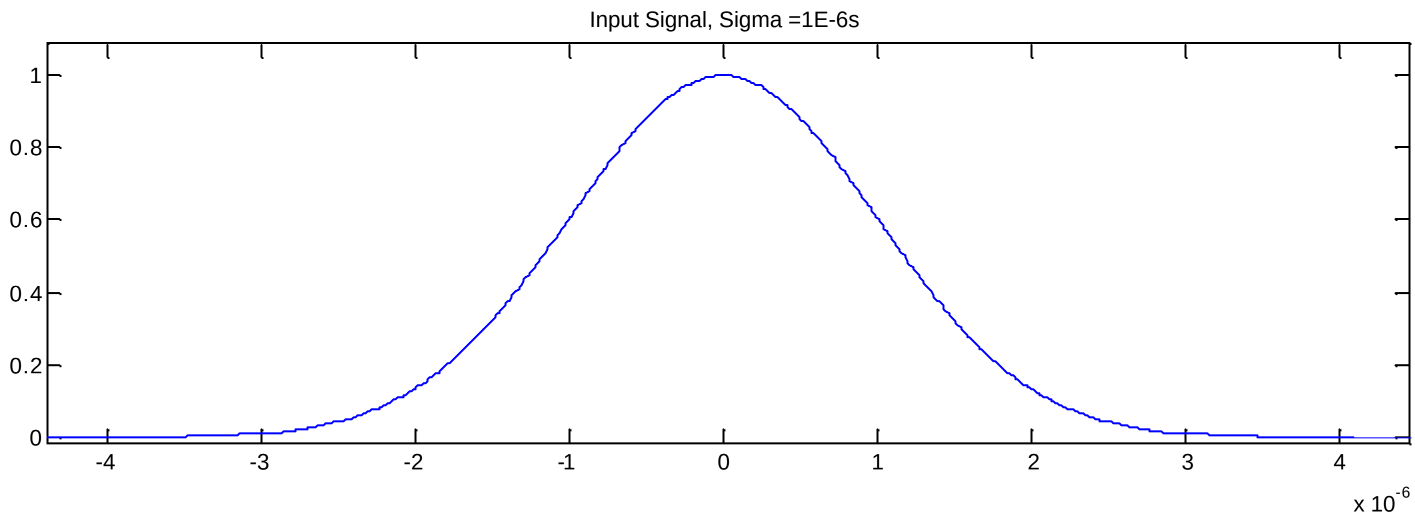
$$\vec{E}(\vec{r},t) = \frac{c_o}{r}\sin q\,\frac{d^2 f(t)}{dt^2}\hat{q}, \quad c_o = const.$$

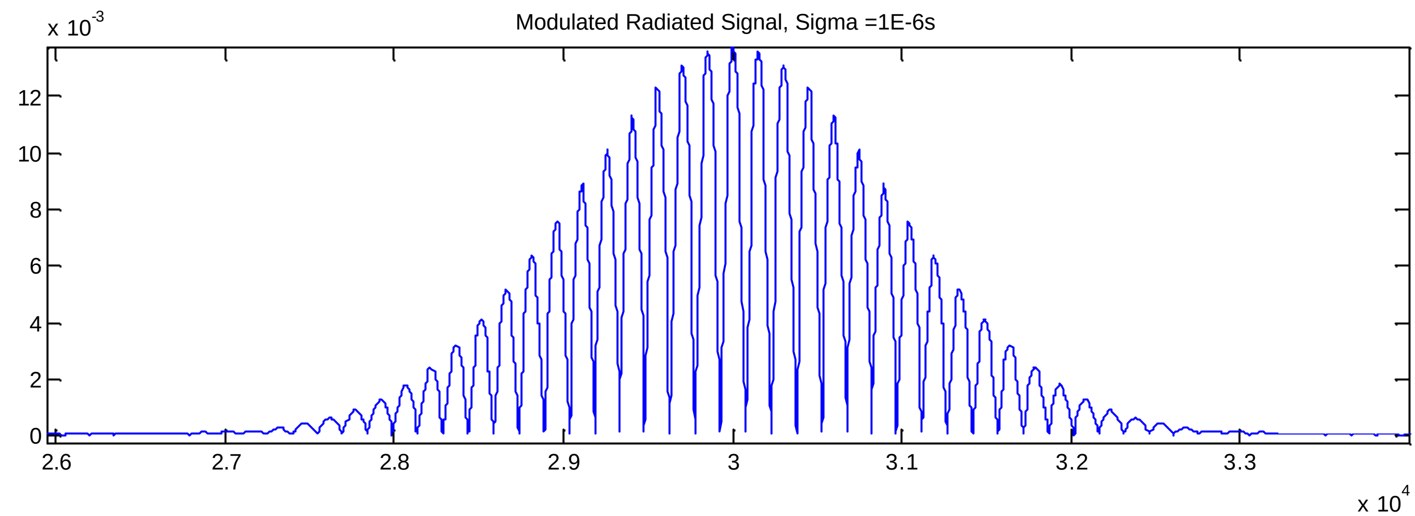
Baseband Response of a Dipole

$$q = \frac{p}{2}$$

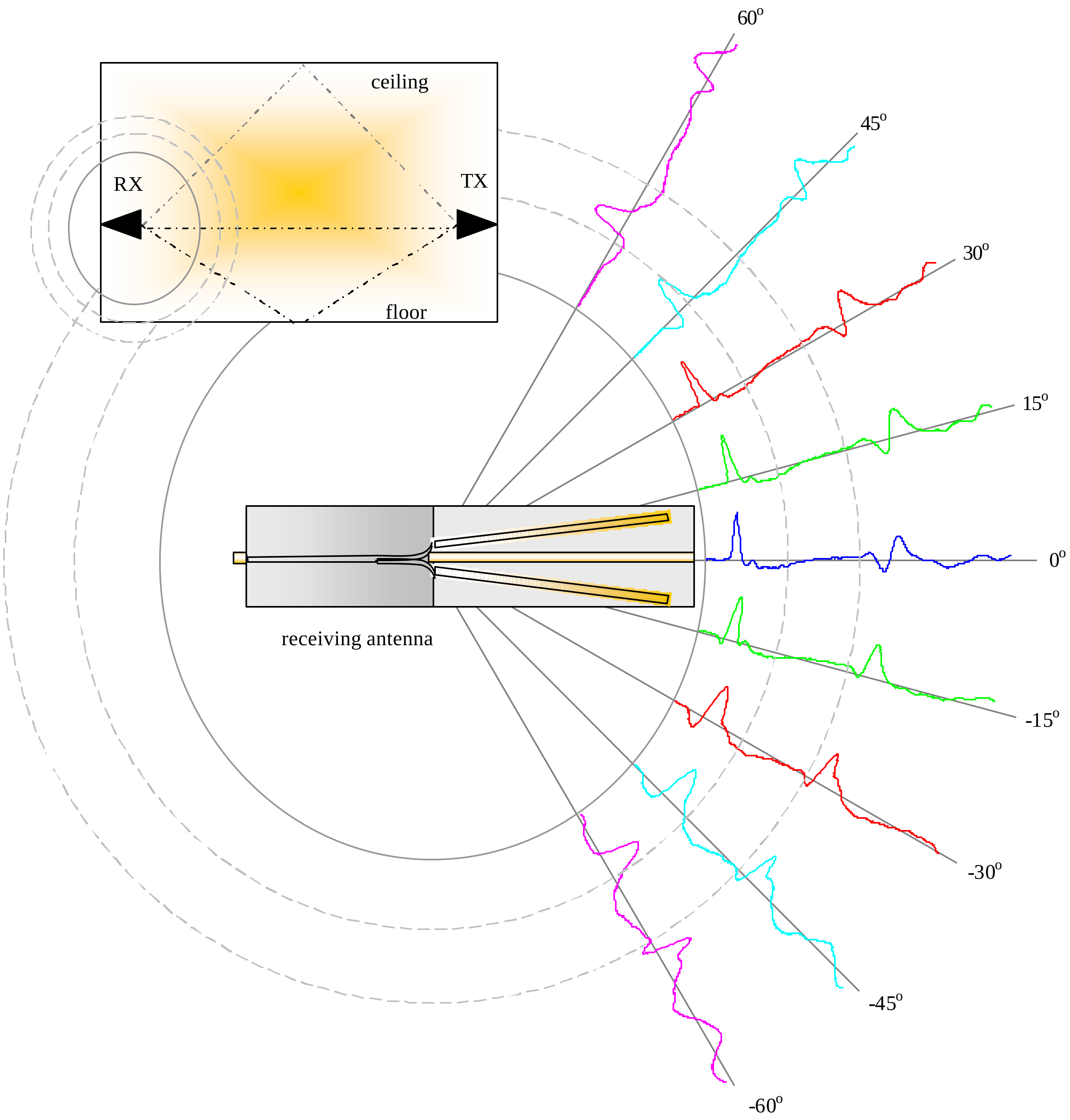


Narrowband Response of the Dipole



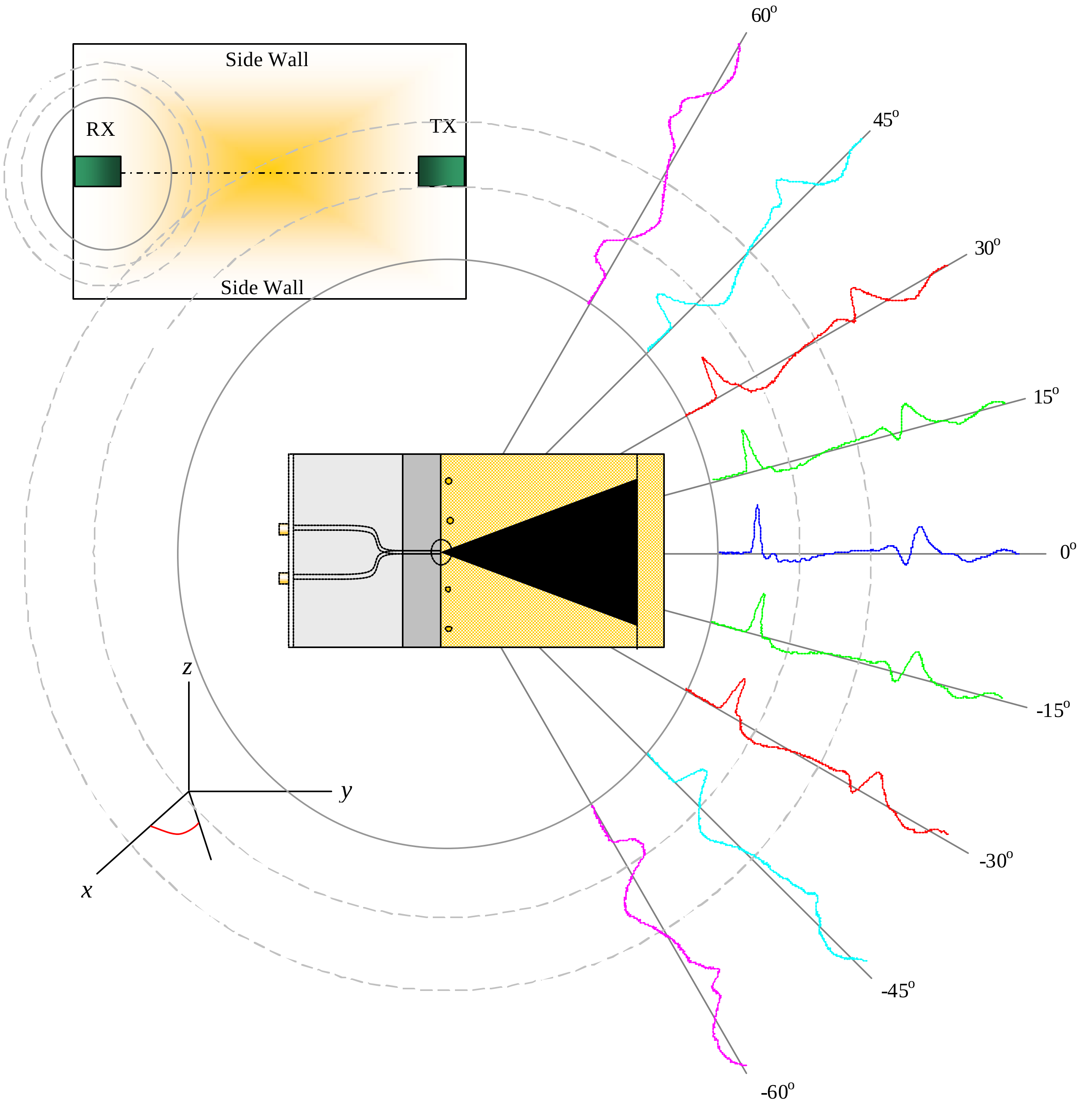


Vertical Angle

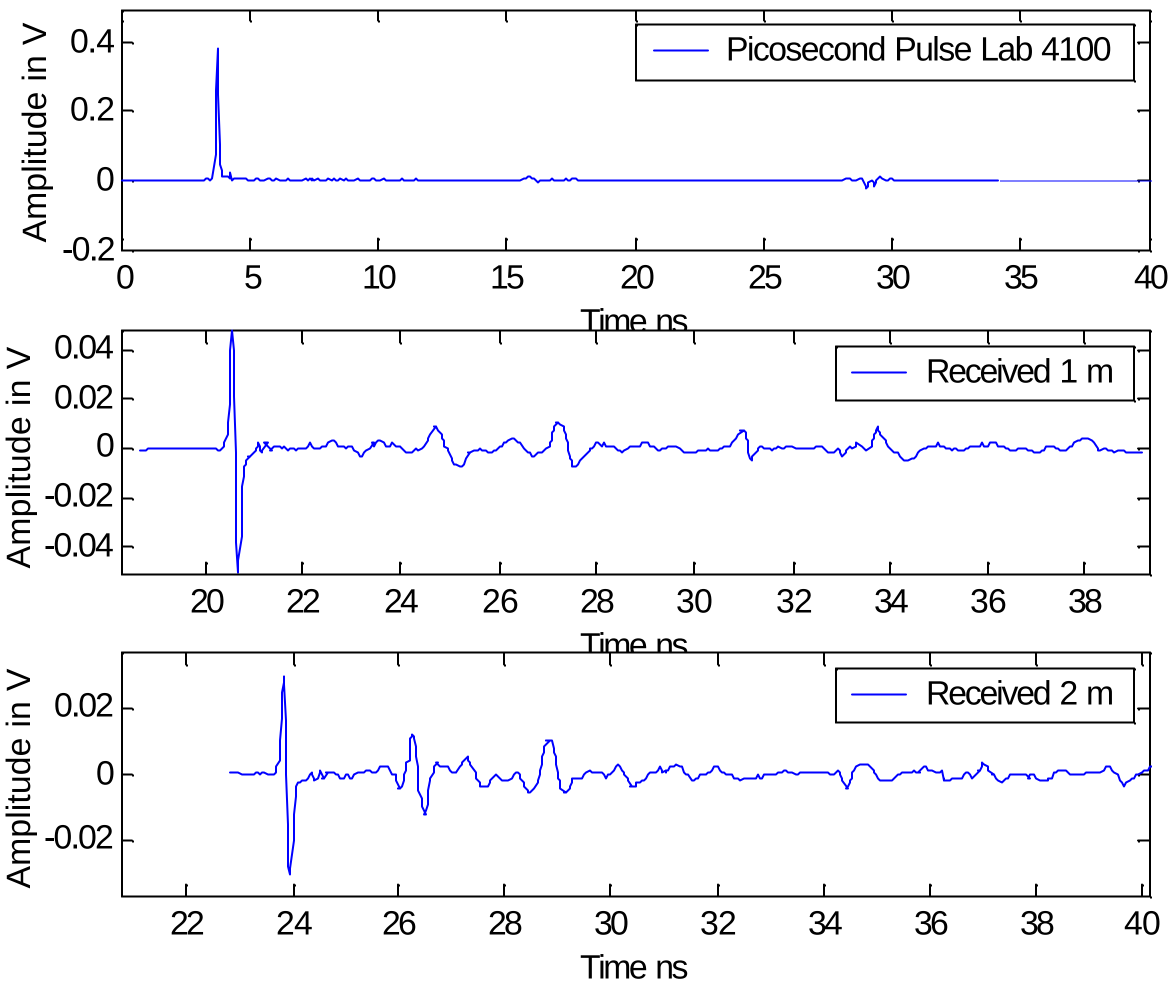


Reflection from the floor

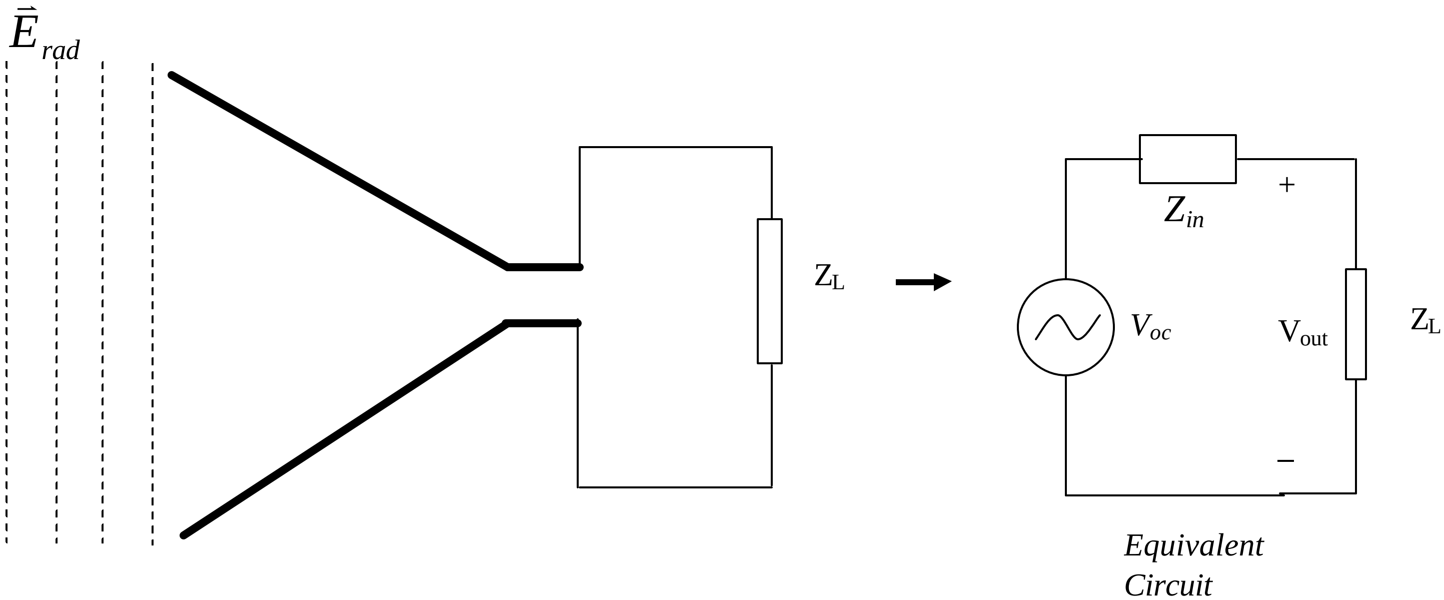
Horizantal Angle



Example Measurements



Receive Antenna



Receive Antenna

$$V_{oc} = \frac{1}{I_{in}} \int \vec{E}_{rad} . \vec{J}_t dv = \vec{E}_{rad} \bullet \vec{L}_{eff} , \qquad L_{eff} = \frac{c}{w} \sqrt{\frac{4pGR_r}{h_o}}$$

$$V_{out} = V_{oc} \frac{Z_L}{Z_L + Z_{in}}$$

For a short dipole: $\boldsymbol{v_{oc}(t) \propto \frac{d}{dt} E_{rad} \propto \frac{d^3}{dt^3} v_{in}(t)}$.

For a TEM Horn : $\boldsymbol{v_{oc}(t) \propto E_{rad} \propto \frac{d}{dt} v_{in}(t)}$.