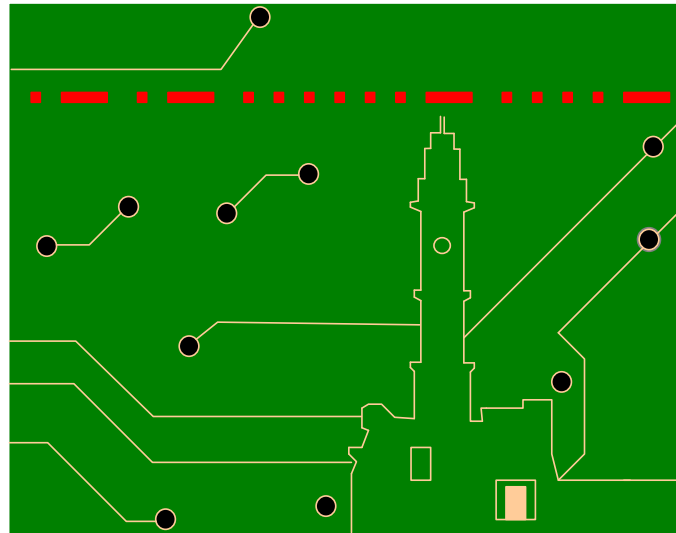


ΤΗΛ412 Ανάλυση & Σχεδίαση (Σύνθεση) Τηλεπικοινωνιακών Διατάξεων

Διαλέξεις 8-9



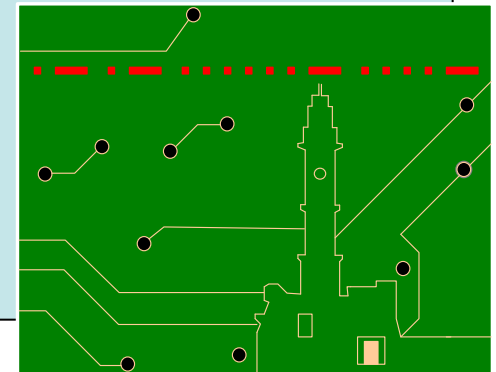
Άγγελος Μπλέτσας

ΗΜΜΥ Πολυτεχνείου Κρήτης, Φθινόπωρο 2014

Διαλέξεις 8-9 – Κεραίες

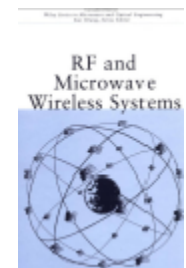
(Από την οπτική γωνία του μηχανικού!)

- Εξισώσεις Helmholtz & Maxwell (&vector calculus).
- Far Field Coupling.
- Antenna Characteristics: VSWR, RL, Efficiency, Gain, Bandwidth, HPBW, Polarization.
- Rough Estimation in High-Gain Antennas.
- Polarization Mismatch

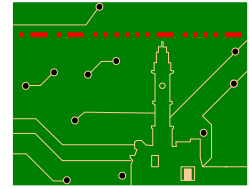


Για την σημερινή διάλεξη έχει χρησιμοποιηθεί υλικό κυρίως από το βιβλίο

Kai Chang, “RF and Microwave Wireless Systems”, Wiley Series in Microwave and Optical Engineering, John Wiley & Sons, 2000.



Βασική ερώτηση μαθήματος



RADIO NEWS FOR FEBRUARY, 1934 403

LEARN RADIO FROM REAL RADIO ENGINEERS

HERE THEY ARE:
 Dr. C. V. Mackenzie, Chief Radio Engineer, General Electric Company
 (Westinghouse)
 Kenneth C. Leach, Chief Engineer, General Electric Co. (Radio Division)
 Clarence B. Shattuck, Chief Engineer, General Electric Co. (Radio Division)
 Earl H. Smith, Chief Engineer, General Electric Co. (Radio Division)
 Harry H. Mearns, Chief Engineer, Radio Division, K.W. Industries
 R. W. Condit, Chief Engineer, General Electric Company
 (Westinghouse)
 H. E. Thibault, Chief Engineer, Radio Division, General Electric Company
 F. D. Williams, Chief Engineer, Radio Division, General Electric Company

LET THESE ENGINEERS RIGHT FROM THE HEART OF THE BIG RADIO INDUSTRY Train You at Home for GOOD PAY RADIO WORK
MANY R. T. I. TRAINED MEN MAKE \$35 TO \$75 A WEEK

If you're dissatisfied with small pay — work that's getting you nowhere — lay-off and uncertain income — here's an opportunity that's too good to miss. At the cost of only the time it takes you to mail the coupon, you can get my big FREE book, "RADIO'S FUTURE AND YOURS." This book tells you how you can learn at home to make more money almost at once in Radio — whether you want to make Radio your life's work, or use it to pick up an extra \$5 to \$20 a week in your spare time.

"RADIO IS GROWING BY LEAPS AND BOUNDS!"
my Radio Craft Magazine — It has forged ahead even in depression years. Where only a few hundred men were employed a short time ago, thousands are employed today. Where a few years ago a hundred jobs paid \$35 to \$75 a week — there are thousands of such jobs today. And more new jobs being created all the time — full time jobs and spare time jobs. Get my book and see how easy it is to learn at home for this good-pay work.

R. T. I. TRAINING IS "SHOP TRAINING" FOR THE HOME

It comes to you right from the Radio Industry — right out of the factories where Radio sets and other vacuum-tube devices are made. It was planned and prepared for you by big radio engineers in these factories, most of whom are the Chief Engineers of these great Radio plants. And NOW these same engineers are actually supervising R-T-I Training. Which means that trained in the R-T-I way you'll be trained — just as the Radio Industry wants you trained — just as the Radio Industry itself would train you if it was doing the job.

4 BIG WORKING OUTFITS INCLUDED
 There are probably the biggest and most expensive Working Outfits ever included with a home-training course. You can then to build up testing equipment — to experiment with — to do actual Radio work. It's Shop Training for the home.

PHOTO PICTURES, P. A. SYSTEMS, SOUND CELLS, TELEVISION, ETC. ALL INCLUDED

Radio service work is just the starting point in R-T-I Training. From there we take you up through the very latest developments in Radio, and then on into the new and larger field of Electronics — Sound Pictures, Public Address Systems, Photo Cells, and Television. This feature alone makes R-T-I the outstanding home training in Radio.

YOU GET "QUICK RESULTS!"
 C. E. Head, 51 Third St., Alexandria, La., says: "Made my first money, 11 days after starting your training — cleared \$14.25."
 Frank E. Alexander, Lake, Ill., writes: "Doubtful my pay in less than six months."
 Harry L. Stark, Ft. Wayne, Ind., writes: "Now making three times as much money as I was when I started your training."

AGE OR LACK OF EDUCATION NO HANDICAP

You don't have to be a high school graduate. It isn't necessary that you should have finished the grades. My Training in Radio is so simple, so easy, and so practical, that it offers every man, regardless of age, education, or previous experience, the chance to get out of a small-pay, menial job, into good pay, big future work in Radio.

YOUR MONEY BACK IF YOU ARE NOT SATISFIED

That's my way of doing business. And I'll give you that agreement in writing — an agreement to refund every penny of your tuition if, on completion of my Training, you are not entirely satisfied.

INVESTIGATE! Learn why R-T-I Training is different. Find out why R-T-I Trained men get "Quick Results" and "Big Results." Send today for my big book "Radio's Future and Yours." The book is free.

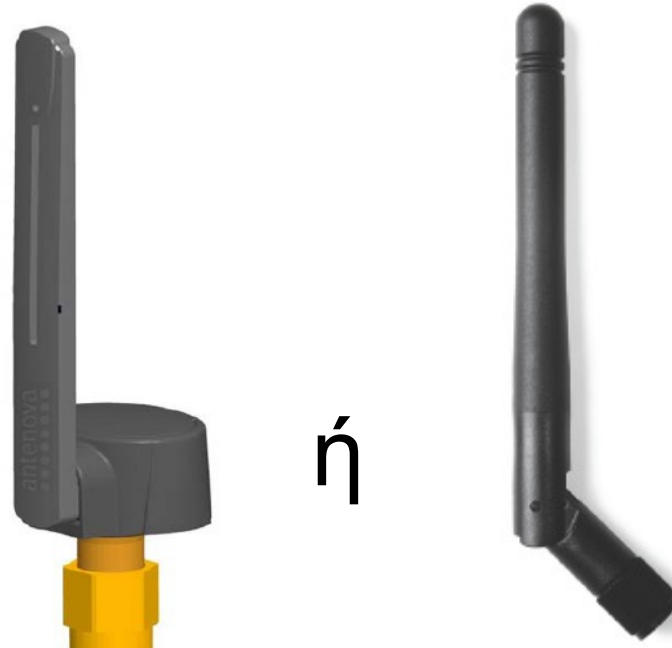
RAY D. SMITH, President
 Radio & Television Institute, Chicago

MAIL COUPON FOR MY FREE BOOK

On your copy of "Radio's Future and Yours" I have put about Radio's amazing opportunities. In sending my Coupon, it tells what R. T. I. means and what you can do. It's FREE. It's the only method known RIGHT NOW!

Ray D. Smith, President,
 RADIO and TELEVISION INSTITUTE, (R. T. I.)
 258 Lawrence Ave., Dept. 41, Chicago, Ill.
 Without obligation on my kind-ness, send me a copy of "Radio's Future and Yours." I am interested in your home training and the opportunity you get with it in the great field of Radio for the R. T. I. Trained man.

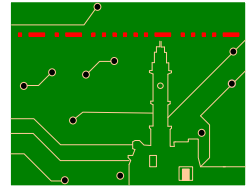
Name _____
 Address _____
 City _____ State _____



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Κεραίες 2.4-2.5GHz



	Typical performance
Peak gain	2.2 dBi
Average gain	-1.0 dBi
Average efficiency	80%
Maximum Return Loss	-13 dB
Maximum VSWR	1.6:1



Frequency [GHz]	Gain [dBi]	Impedance [Nom]	VSWR	Polarization	Electrical Length	Radiation
2.4 – 2.5	2.0	50 Ω	≤ 2.0	Vertical	¼, dipole	Omni

Ορισμός

- Κεραία = διεπαφή (i.e. interface) μεταξύ κυμάτων/σημάτων.
- Κεραία \equiv συντονισμός
- Κεραία = μέγιστη ακτινοβολία.
- Κυματοδηγός = ελάχιστη ακτινοβολία.
- Χαρακτηρισμός: γεωμετρία, κέρδος, λωβός, εύρος ζώνης.

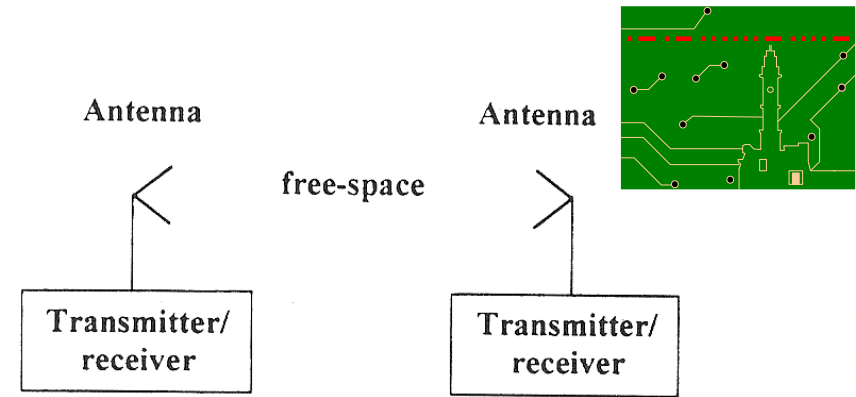
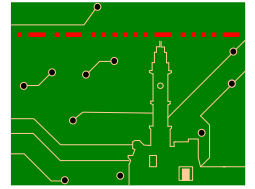


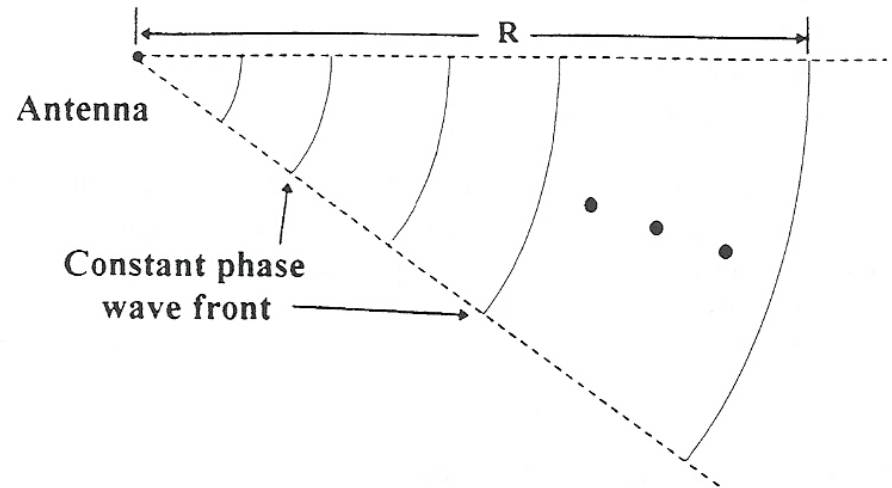
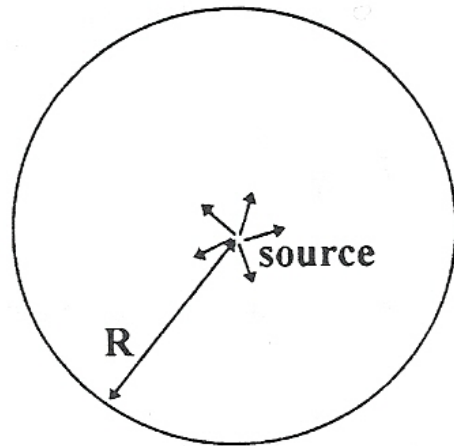
FIGURE 3.1 Typical wireless system.

<p><i>Dipole</i></p>	<p><i>Loop</i></p>	<p><i>Patch</i></p>
<p><i>Slot</i></p>	<p><i>Spiral</i></p>	<p><i>Helix</i></p>
<p><i>Yagi-Uda</i></p>	<p><i>Horn</i></p>	<p><i>Notch</i></p>

Ισοτροπικός Ακτινοβολητής και Επίπεδα Κύματα



$$\nabla^2 \vec{E} + k_0^2 \vec{E} = 0$$

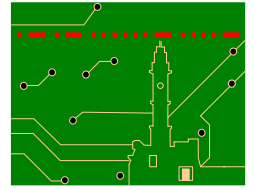


- Θεωρητικό (και μόνο) εργαλείο.
- Μέτωπο κύματος σφαιρικό.
- Πυκνότητα ισχύος:

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

- Μεγάλο $R \Rightarrow$ επίπεδο κύμα (όχι σφαιρικό)
- Η/Μ πεδίο: Εξίσωση Κύματος (Helmholtz).

Θυμάστε τις εξισώσεις του Maxwell?



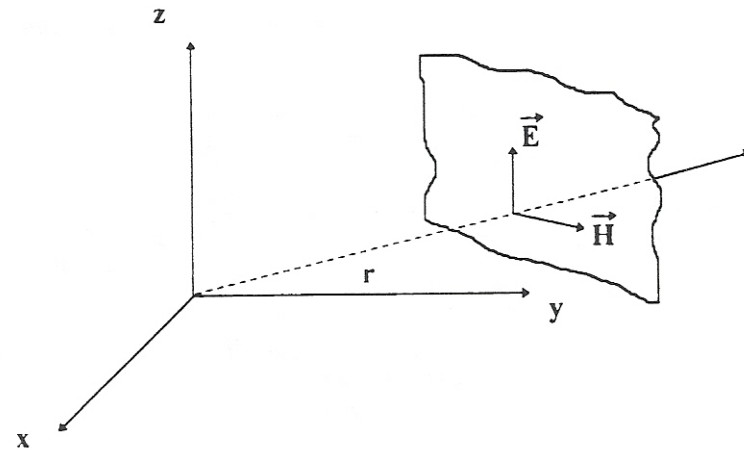
Div: Ροή διανυσματικού πεδίου ανά μονάδα όγκου

$$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon} \quad \text{Gauss' law}$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad \text{Faraday's law}$$

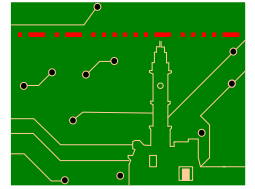
$$\nabla \times \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{J} \quad \text{Ampere's law}$$

$$\nabla \cdot \vec{B} = 0 \quad \text{flux law}$$



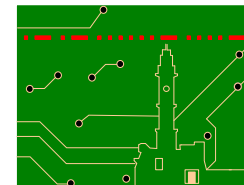
Curl: Κυκλοφορία διανυσματικού πεδίου ανά μονάδα επιφάνειας

Basic E/M Units



- charge density ρ (Coulomb/m³), current density J (Ampere/m²)
- permittivity ϵ : Farad/m
- Electric Field E : Volt/m
- permeability μ : Henry/m
- Magnetic Field H : Ampere/m
- Magnetic flux density B =magnetic flux/surface= μH : Tesla
- Magnetic flux Φ : Weber = Henry Ampere
- Electric Displacement D = ϵE : Coulomb/m²

Θυμάστε διανυσματική ανάλυση?



Let $f: \mathbf{R}^3 \rightarrow \mathbf{R}$ and $\mathbf{F}: \mathbf{R}^3 \rightarrow \mathbf{R}^3$. Write $\mathbf{F} = (f_1, f_2, f_3)$.
Similarly for g and \mathbf{G} .

Define:

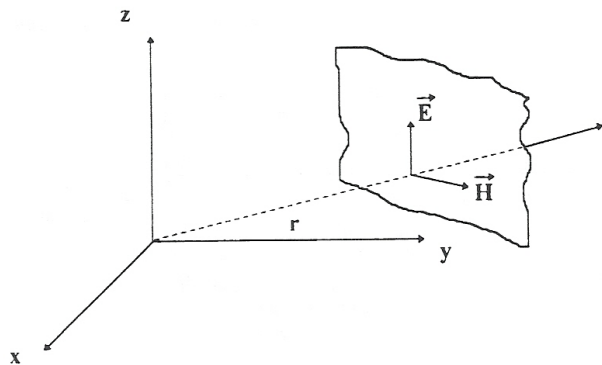
$$\text{grad}(f) \equiv \nabla f = \left(\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}, \frac{\partial f}{\partial z} \right)$$

$$\text{div}(\mathbf{F}) \equiv \nabla \cdot \mathbf{F} = \frac{\partial f_1}{\partial x} + \frac{\partial f_2}{\partial y} + \frac{\partial f_3}{\partial z}$$

$$\text{curl}(\mathbf{F}) \equiv \nabla \times \mathbf{F} = \left(\frac{\partial f_3}{\partial y} - \frac{\partial f_2}{\partial z}, \frac{\partial f_1}{\partial z} - \frac{\partial f_3}{\partial x}, \frac{\partial f_2}{\partial x} - \frac{\partial f_1}{\partial y} \right)$$

$$\text{laplace}(f) \equiv \nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} + \frac{\partial^2 f}{\partial z^2}$$

$$\text{laplace}(\mathbf{F}) \equiv \nabla^2 \mathbf{F} = (\nabla^2 f_1, \nabla^2 f_2, \nabla^2 f_3)$$



Θυμάστε διανυσματική ανάλυση?

Let $\phi(x,y,z)$ be a scalar field. The gradient is a vector

$$\text{grad } \phi = \left(\frac{\partial \phi}{\partial x}, \frac{\partial \phi}{\partial y}, \frac{\partial \phi}{\partial z} \right),$$

it is the derivative of ϕ in each direction. The gradient of a scalar field is a vector field. An alternative notation is to use the *del* or *nabla* operator, $\nabla \phi = \text{grad } \phi$.

Divergence of a vector field

Let $F(x,y,z)$ be a vector field, continuously differentiable with respect to x,y and z . Then the divergence of F is defined by

$$\text{div } F = \frac{\partial F_1}{\partial x} + \frac{\partial F_2}{\partial y} + \frac{\partial F_3}{\partial z}.$$

Laplacian



$$\Delta f = \nabla^2 f = \nabla \cdot \nabla f,$$

$$\Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} + \frac{\partial^2 f}{\partial z^2}$$

div F is a scalar field it can also be written as $\text{div } \mathbf{F} = \nabla \cdot \mathbf{F}$

$$\Delta f = \frac{1}{\rho} \frac{\partial}{\partial \rho} \left(\rho \frac{\partial f}{\partial \rho} \right) + \frac{1}{\rho^2} \frac{\partial^2 f}{\partial \theta^2} + \frac{\partial^2 f}{\partial z^2}$$

Curl of a vector field

$$\Delta f = \frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial f}{\partial r} \right) + \frac{1}{r^2 \sin \varphi} \frac{\partial}{\partial \varphi} \left(\sin \varphi \frac{\partial f}{\partial \varphi} \right) + \frac{1}{r^2 \sin^2 \varphi} \frac{\partial^2 f}{\partial \theta^2}$$

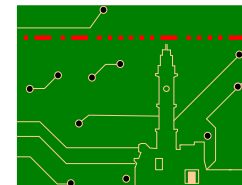
Let $F(x,y,z)$ be a vector field, continuously differentiable with respect to x,y and z . Then the **curl** of F is defined by

$$\begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ F_1 & F_2 & F_3 \end{vmatrix} = \text{curl } F = \left(\frac{\partial F_3}{\partial y} - \frac{\partial F_2}{\partial z} \right) \mathbf{i} - \left(\frac{\partial F_3}{\partial x} - \frac{\partial F_1}{\partial z} \right) \mathbf{j} + \left(\frac{\partial F_2}{\partial x} - \frac{\partial F_1}{\partial y} \right) \mathbf{k}$$

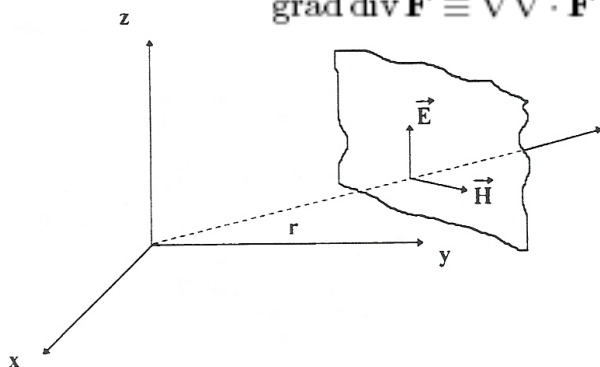
curl F is a vector field it can also be written as $\nabla \times F$.

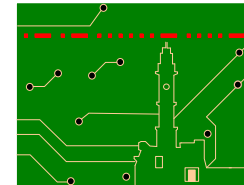
Notice that $\nabla \cdot (\nabla \times \mathbf{F}) = 0$

Θυμάστε διανυσματική ανάλυση?



$$\begin{aligned}
 \text{grad}(f + g) &\equiv \nabla(f + g) &= \nabla f + \nabla g \\
 \text{div}(\mathbf{F} + \mathbf{G}) &\equiv \nabla \cdot (\mathbf{F} + \mathbf{G}) &= \nabla \cdot \mathbf{F} + \nabla \cdot \mathbf{G} \\
 \text{curl}(\mathbf{F} + \mathbf{G}) &\equiv \nabla \times (\mathbf{F} + \mathbf{G}) &= \nabla \times \mathbf{F} + \nabla \times \mathbf{G} \\
 \text{grad}(fg) &\equiv \nabla(fg) &= f\nabla g + g\nabla f \\
 \text{div}(f\mathbf{G}) &\equiv \nabla \cdot (f\mathbf{G}) &= \nabla f \cdot \mathbf{G} + f\nabla \cdot \mathbf{G} \\
 \text{curl}(f\mathbf{G}) &\equiv \nabla \times (f\mathbf{G}) &= \nabla f \times \mathbf{G} + f\nabla \times \mathbf{G} \\
 \text{grad}(\mathbf{F} \cdot \mathbf{G}) &\equiv \nabla(\mathbf{F} \cdot \mathbf{G}) &= (\mathbf{F} \cdot \nabla)\mathbf{G} + (\mathbf{G} \cdot \nabla)\mathbf{F} + \mathbf{F} \times (\nabla \times \mathbf{G}) + \mathbf{G} \times (\nabla \times \mathbf{F}) \\
 \text{div}(\mathbf{F} \times \mathbf{G}) &\equiv \nabla \cdot (\mathbf{F} \times \mathbf{G}) &= \mathbf{G} \cdot \nabla \times \mathbf{F} - \mathbf{F} \cdot \nabla \times \mathbf{G} \\
 \text{curl}(\mathbf{F} \times \mathbf{G}) &\equiv \nabla \times (\mathbf{F} \times \mathbf{G}) &= \mathbf{F}(\nabla \cdot \mathbf{G}) - \mathbf{G}(\nabla \cdot \mathbf{F}) + (\mathbf{G} \cdot \nabla)\mathbf{F} - (\mathbf{F} \cdot \nabla)\mathbf{G} \\
 \text{div grad } f &\equiv \nabla \cdot \nabla f &= \nabla^2 f = \text{laplace } f \\
 \text{curl grad } f &\equiv \nabla \times \nabla f &= 0 \\
 \text{div curl } \mathbf{F} &\equiv \nabla \cdot (\nabla \times \mathbf{F}) &= 0 \\
 \text{curl}^2 \mathbf{F} &\equiv \nabla \times (\nabla \times \mathbf{F}) &= \nabla \nabla \cdot \mathbf{F} - \nabla^2 \mathbf{F} = \text{grad div } \mathbf{F} - \text{laplace } \mathbf{F} \\
 \text{grad div } \mathbf{F} &\equiv \nabla \nabla \cdot \mathbf{F} &= \nabla \times (\nabla \times \mathbf{F}) + \nabla^2 \mathbf{F} = \text{curl}^2 \mathbf{F} + \text{laplace } \mathbf{F}
 \end{aligned}$$





Θυμάστε διανυσματική ανάλυση?

Τα παρακάτω δείχνουν το Intuition...

(curl (rotation)= vector circulation per unit area, div=vector flux per unit of volume, grad=direction of rate of change)

Curl

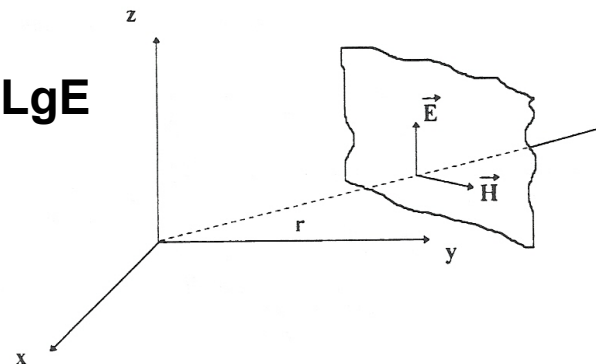
<http://www.youtube.com/watch?v=fYzoiWIBjP8>

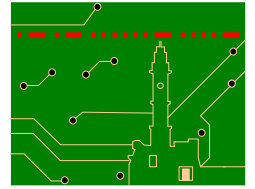
Div

<http://www.youtube.com/watch?v=tOX3RkH2guE>

Grad

<http://www.youtube.com/watch?v=OB8b8aDGLgE>





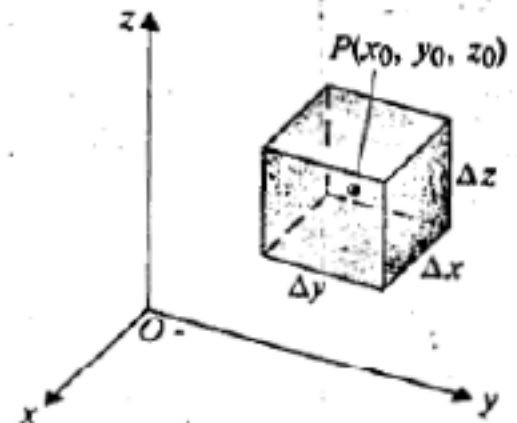
Divergence of \mathbf{A} at a point:

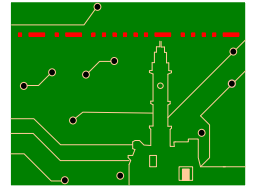
net outward flux of \mathbf{A} per unit volume, when the volume around the point of interest tends to zero.

$$\text{div} \mathbf{A} \triangleq \lim_{\Delta v \rightarrow 0} \frac{\oint_s \mathbf{A} \cdot d\mathbf{s}}{\Delta v}$$

→ The net outward flux
 → Measure of the strength of a flow source

$$\oint_s \mathbf{A} \cdot d\mathbf{s} = \left[\int_{\text{front face}} + \int_{\text{back face}} + \int_{\text{left face}} + \int_{\text{right face}} + \int_{\text{top face}} + \int_{\text{bottom face}} \right] \mathbf{A} \cdot \mathbf{a}_n ds$$





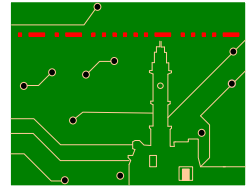
Divergence Theorem (aka Gauss Theorem):
volume integral of of div of vector **A** = flux of **A** through
bounding surface of that volume.

$$\int_v \nabla \cdot \mathbf{A} dv = \oint_s \mathbf{A} \cdot d\mathbf{s}$$

$$\text{div} \mathbf{A} \triangleq \lim_{\Delta v \rightarrow 0} \frac{\oint_s \mathbf{A} \cdot d\mathbf{s}}{\Delta v}$$

→ The net outward flux

→ Measure of the strength of a flow source



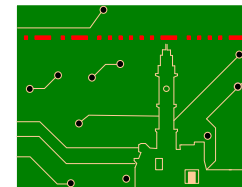
Curl of \mathbf{A} at a point: vector, with
 magnitude = the maximum net circulation of vector \mathbf{A} per unit area
 around that point, as the area tends to zero,
 direction = normal to area, when area is oriented such that circulation is
 maximized.

Circulation of \mathbf{A} around contour C $\equiv \oint_C \mathbf{A} \cdot d\hat{\mathbf{l}}$ \mathbf{A} : force \rightarrow circulation: work
 \mathbf{A} : E-field \rightarrow circulation: electromotive force

Circulation of \mathbf{A} in closed path c = line integral of \mathbf{A} over c .

$$\text{curl } \mathbf{A} \equiv \nabla \times \mathbf{A} = \lim_{\Delta S \rightarrow 0} \frac{1}{\Delta S} \left[\mathbf{a}_n \oint_C \mathbf{A} \cdot d\hat{\mathbf{l}} \right]_{\text{max}}$$

The diagram shows a small, irregularly shaped surface element ΔS in a light blue color. A red vector \mathbf{a}_n points upwards from the center of the surface, representing the normal direction. A red dashed line represents the boundary of the surface, with a red arrow $d\hat{\mathbf{l}}$ indicating the direction of circulation around the boundary.



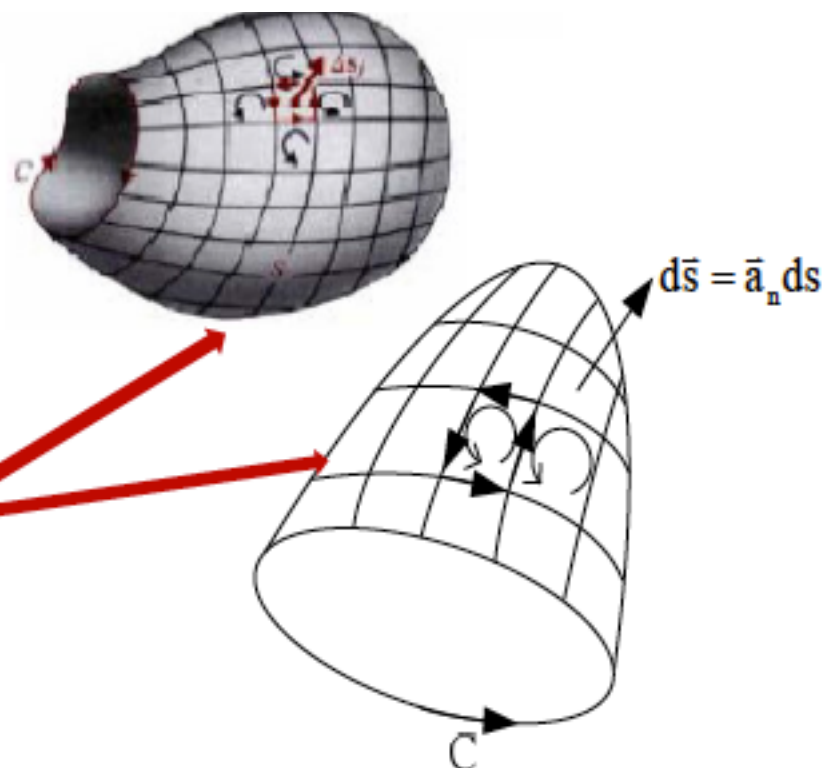
Curl Theorem (aka Stokes Theorem):

the surface integral of curl of a vector over an open surface

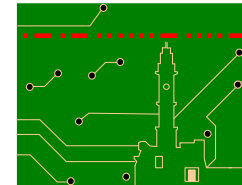
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the closed line integral of the vector over the bounding contour of the surface.

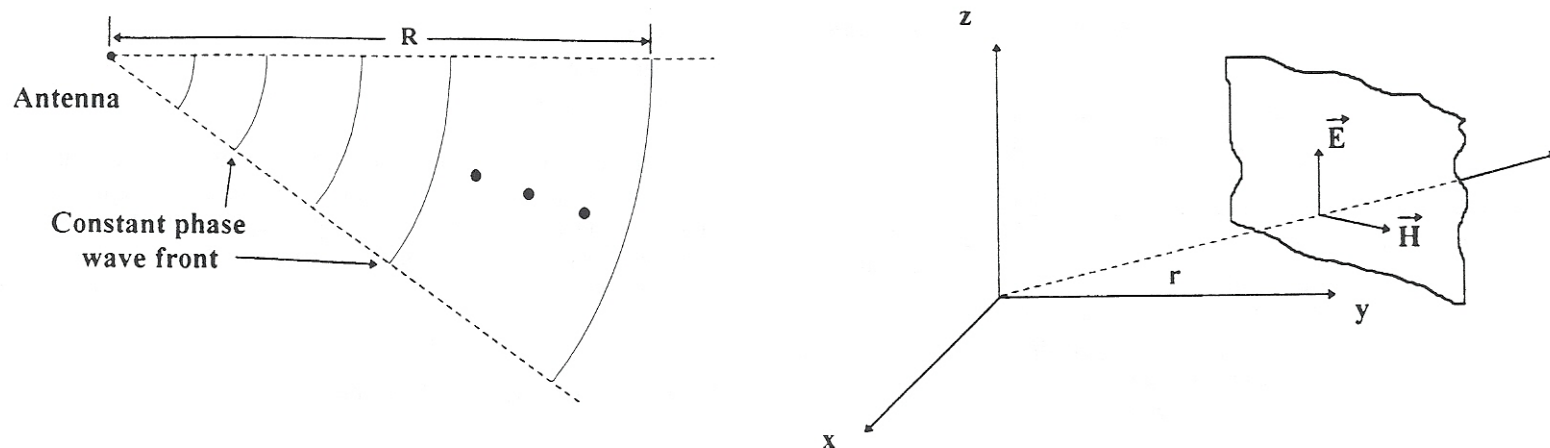
$$\oint_S (\nabla \times \vec{A}) \cdot d\vec{s} = \oint_C \vec{A} \cdot d\vec{\ell}$$



Question: what are the units of $\text{div}(\vec{A})$, $\text{curl}(\vec{A})$?



Εξίσωση Κύματος (Εξίσωση Helmholtz): Επίλυση



$$k_0 = \frac{2\pi}{\lambda_0}, \vec{k}_0 = k_0 \vec{n}_0,$$

$$\vec{E} = \vec{E}_0 e^{-j\vec{k}_0 \cdot \vec{r}},$$

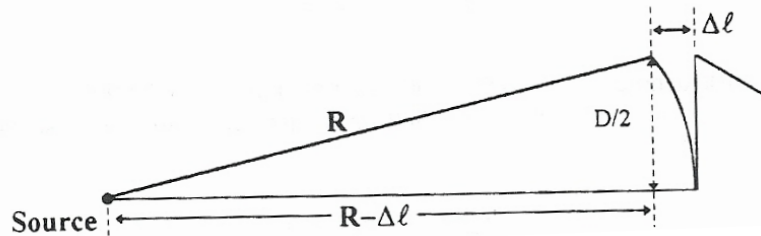
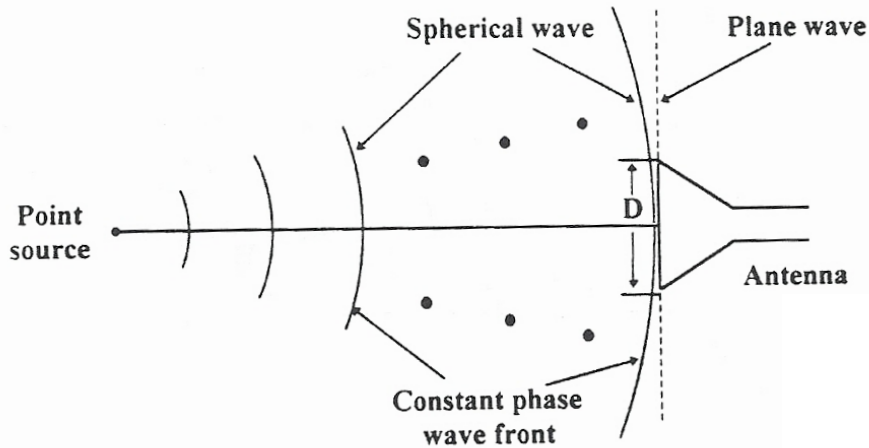
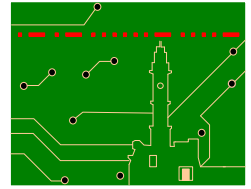
$$\vec{H} = -\frac{1}{j\omega\mu_0} \nabla \times \vec{E} = \sqrt{\frac{\epsilon_0}{\mu_0}} \vec{n} \times \vec{E}. \quad \text{Maxwell}$$

$$\eta_0 = \frac{|\vec{E}|}{|\vec{H}|} = \sqrt{\frac{\mu_0}{\epsilon_0}} = 120\pi. \quad \text{Διαστάσεις σε } \Omega\text{hm}$$

$$P_d = \left| \frac{1}{2} \vec{E} \times \vec{H}^* \right| = \frac{1}{2} \frac{E_0^2}{\eta_0} \equiv \frac{P_t}{4\pi R^2} \Rightarrow E_0 = \frac{\sqrt{60P_t}}{R} = \sqrt{2} E_{\text{rms}}.$$

Λύση Helmholtz

Far Field Region



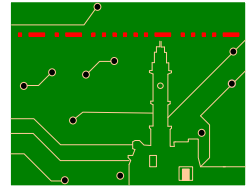
$$R^2 = (R - \Delta l)^2 + \frac{D^2}{4}, R^2 \approx R^2 + (\Delta l)^2 \Rightarrow$$

$$R = \frac{D^2}{8\Delta l}, \Delta l = \frac{1}{16}\lambda_0 \Rightarrow$$

$$R_{\text{far-field}} = \frac{2 D^2}{\lambda_0}.$$

- Region where plane-wave is a “good” approximation!
- Practically, where antenna patterns are independent of distance.

Antenna Analysis (in one minute)



➤ Solution through inhomogeneous Helmholtz equation.

➤ Antenna with volume V and current \mathbf{J} :

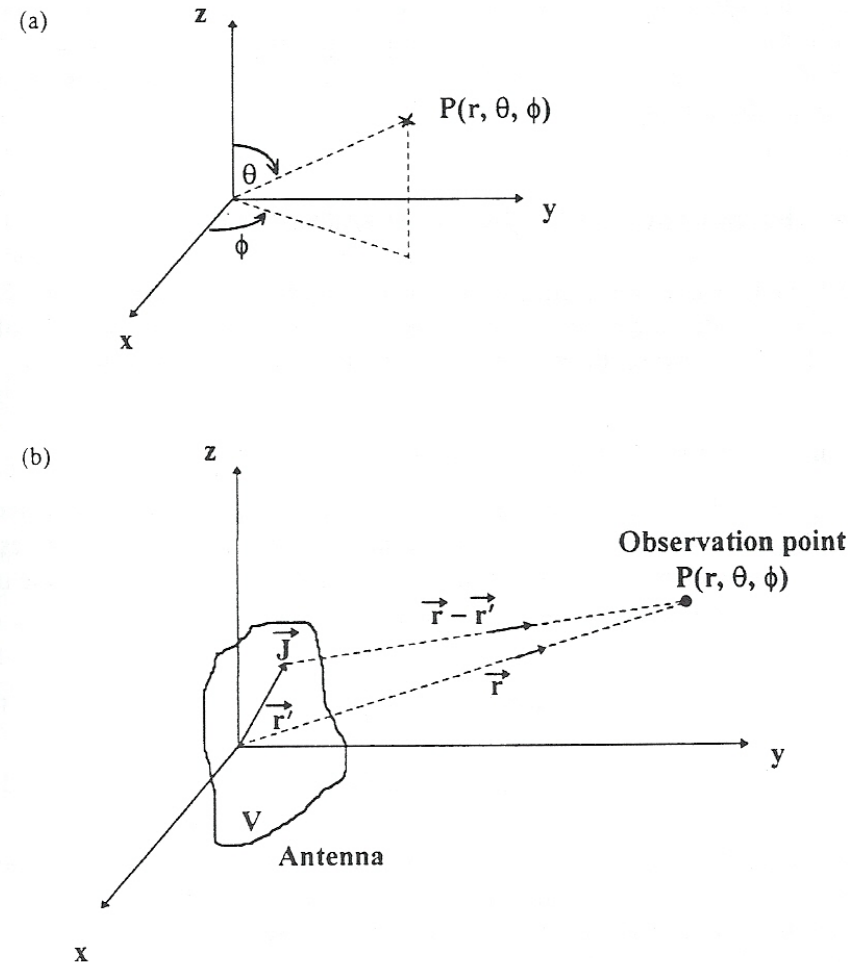
$$\nabla^2 \vec{A} + k_0^2 \vec{A} = -\mu \vec{J},$$

$$\vec{B} = \nabla \times \vec{A} = \mu_0 \vec{H},$$

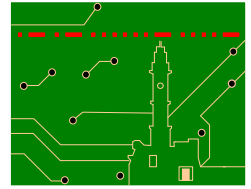
$$\vec{A}(\vec{r}) = \frac{\mu}{4\pi} \int_V \vec{J}(\vec{r}') \frac{e^{-jk_0|\vec{r}-\vec{r}'|}}{|\vec{r}-\vec{r}'|} dV.$$

➤ Current distribution from Antenna geometry.

➤ Numerical methods.



Characteristics: Input VSWR & Impedance



We prove these in next lecture!

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|},$$

$$RL = \pm 20 \log_{10} |\Gamma|,$$

$$Z_{in} = Z_0 \frac{1 + \Gamma}{1 - \Gamma}.$$

Return Loss

$0 < |\Gamma|^2 < 1$,
sign depends
on book/context

- $|\Gamma|^2$ shows the percentage of power lost due to mismatch (reflection).
- power coupled to antenna = $(1 - |\Gamma|^2)$ times the power delivered from source.
- Typically, VSWR is less than 2:1.
- Example: VSWR = 2:1 means that 11% of delivered tx power to antenna is lost!

Characteristics: Bandwidth

- Various meanings, depending on context.
- Most common: impedance bandwidth.
- Impedance bandwidth: range of frequencies where VSWR below a threshold.
- Other definitions based on gain, efficiency, patterns etc.
- Operational bandwidth usually smaller.

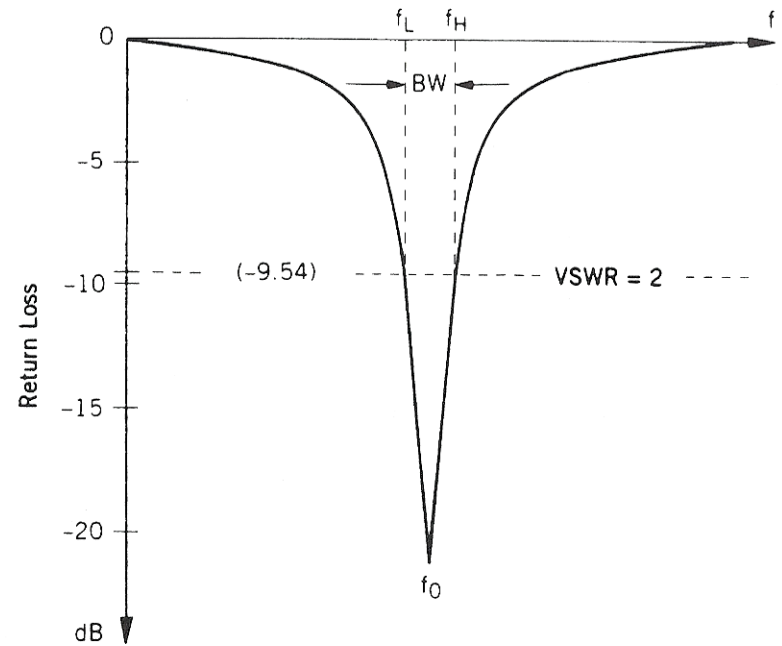
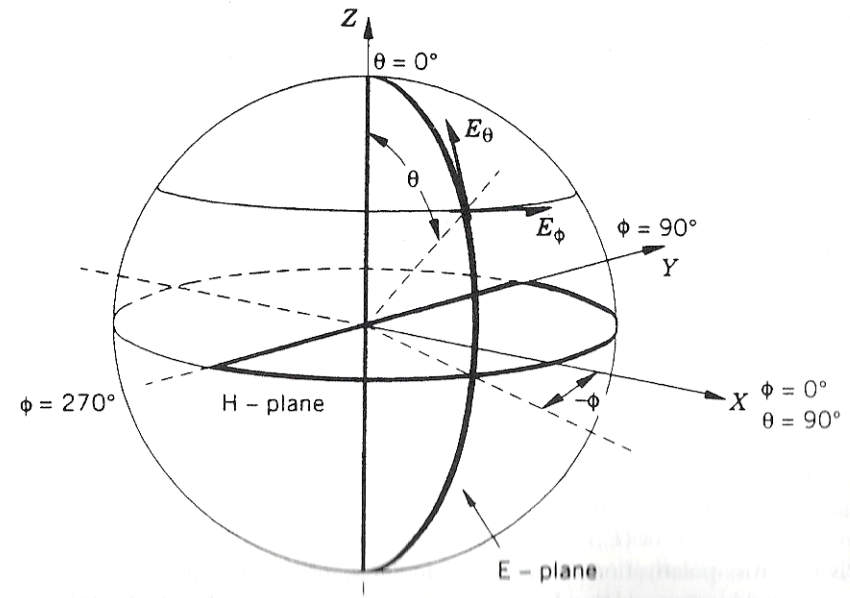


FIGURE 3.8 VSWR = 2 bandwidth [2].



Characteristics: Power Radiation Patterns

- Remember: far-field electric characteristics are independent of distance.
- Typically, plot power density (Poynting vector across a sphere, centered at the ant.)
- Simpler approach: draw electric and/or magnetic field at cut planes where the field is maximized.
- E-plane: E_θ plane.
- Cross-polarization component: E_ϕ

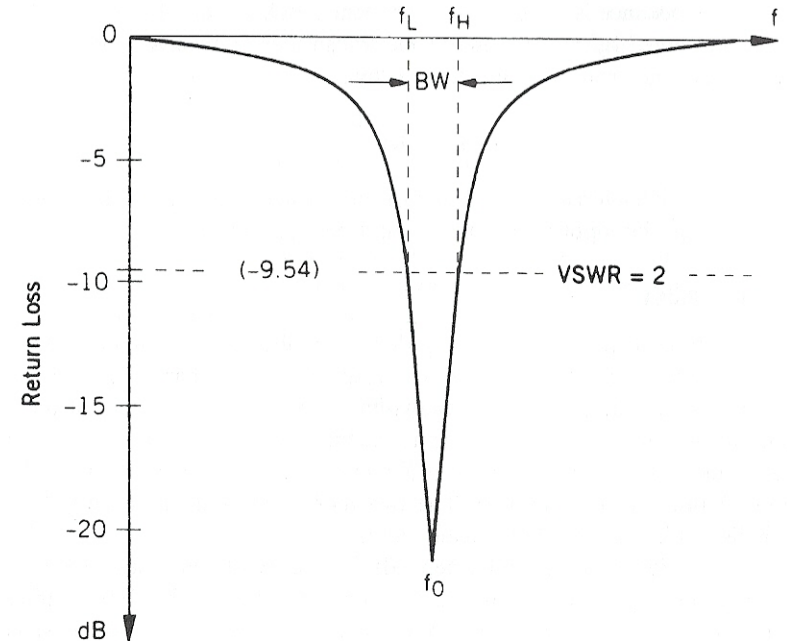
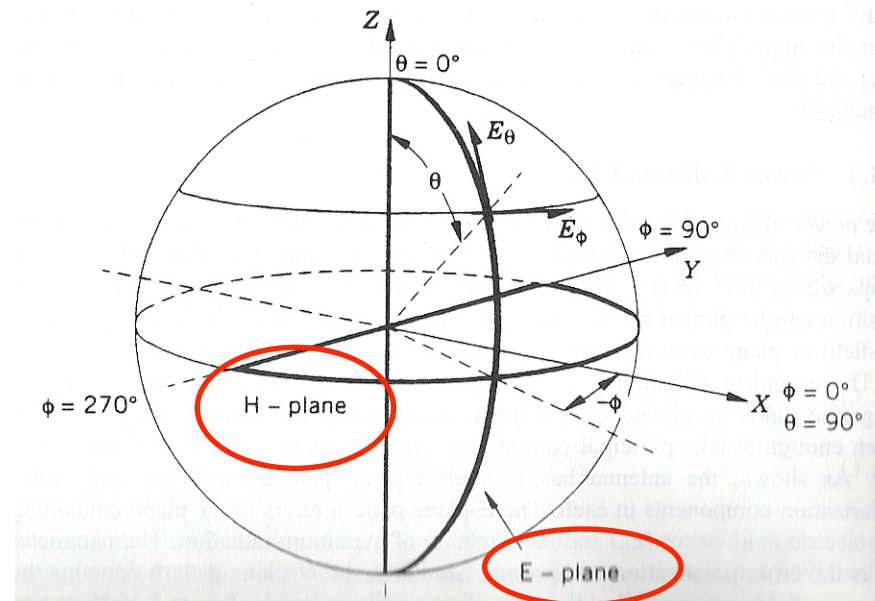
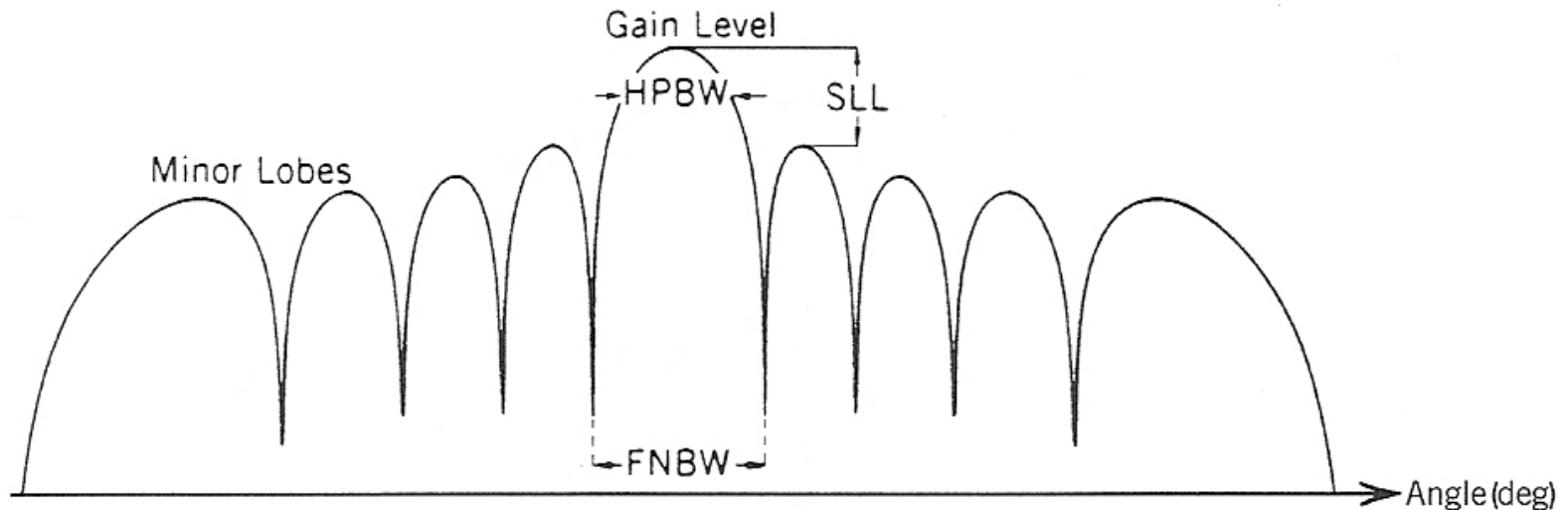
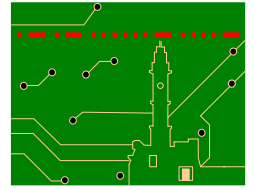


FIGURE 3.8 VSWR = 2 bandwidth [2].

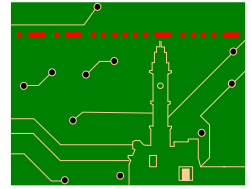


Characteristics: Half-power Beamwidth and Side Lobe Level (SLL)



- HPBW: the range in degrees such that the radiation drops to one-half.
- SLL: the number of decibels below the main peak of the side peaks.

Characteristics: Directivity, Gain, Efficiency



$$\text{Poynting power density} = \vec{S}(\theta, \phi) = \frac{1}{2} \Re [\vec{E} \times \vec{H}^*],$$

$$D(\theta, \phi) = \frac{S(\theta, \phi)}{P_t/4\pi R^2},$$

$$D_{\max} = \frac{\max |\vec{S}(\theta, \phi)|}{P_t/4\pi R^2}.$$

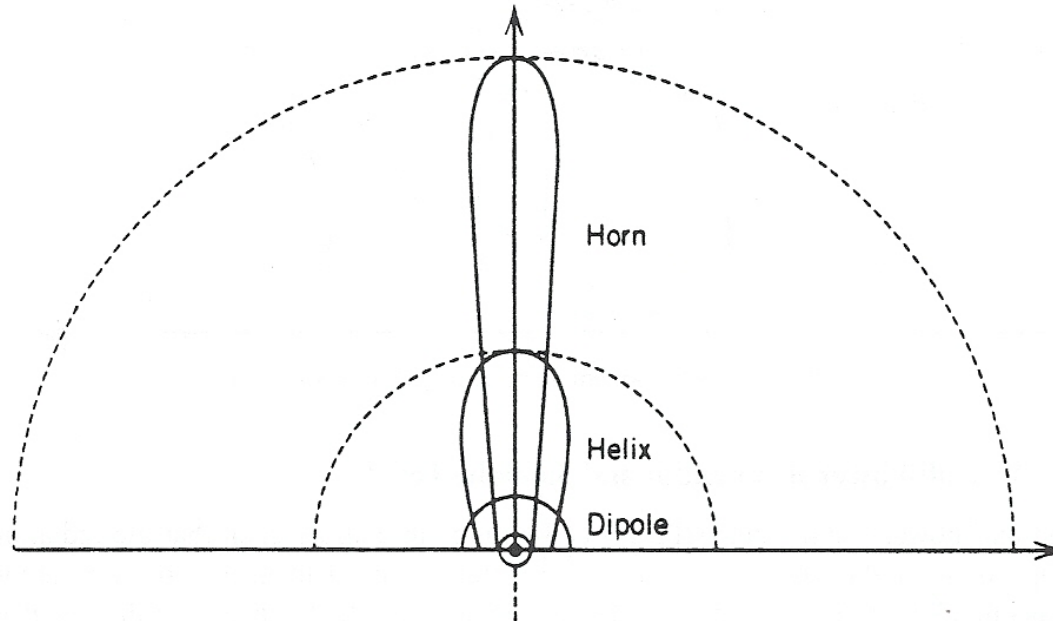
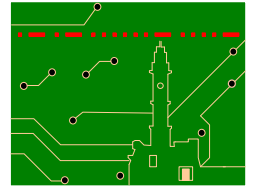
Note: $P_t = P_{\text{rad}}$

$$\text{efficiency } \eta = \frac{P_{\text{rad}}}{P_{\text{in}}} = \frac{P_{\text{rad}}}{P_{\text{rad}} + P_{\text{loss}}}.$$

$$\text{Gain } G = \eta D_{\max}.$$

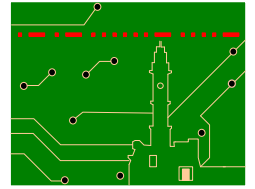
- Gain and efficiency connect radiated power with ant input power.
- For example: $G P_t/4\pi R^2$ is radiated power density towards maximum radiation direction (Note: P_t is total input power $P_t = P_{\text{rad}} + P_{\text{loss}}$).
- Why don't we always maximize gain?

Characteristics: gain-bw tradeoff



- Gain-beamwidth tradeoff: maximizing one, minimizes the other.
- Gain-bandwidth tradeoff also exists (fundamental).
- Thus, maximizing ant gain comes at the cost of reduced bandwidth and increased HPBW.

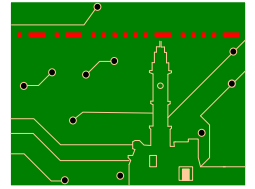
Characteristics: Rough Estimation of High-Gain Ant



$$\text{HPBW} \approx K_1 \frac{\lambda_0}{D}, \quad G \approx \frac{K_2}{\theta_1 \theta_2}$$

- $K_1 \approx 70^\circ$, D ant dimension at the plane of interest.
- $K_2 \approx 30,000$, θ_1, θ_2 are HPBW across the two orthogonal principal planes.

Characteristics: Effective Area, Polarization

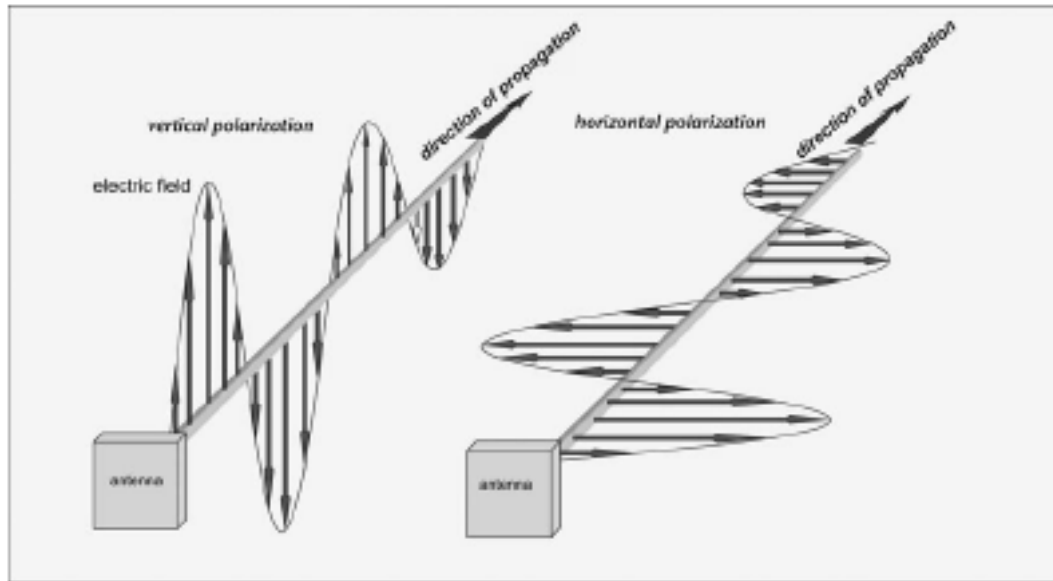
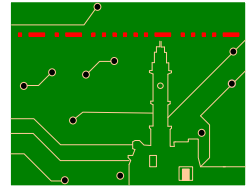


- Effective area proportional, but smaller, than physical area.
- Friis Equation is derived through A_e

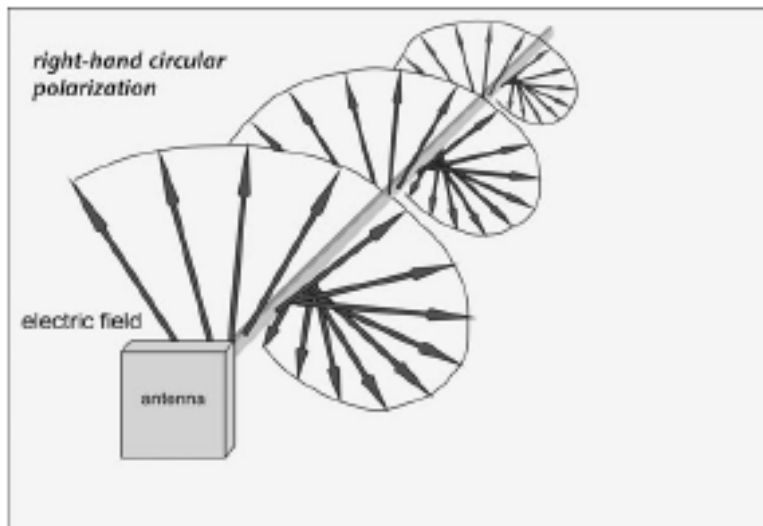
$$G = \frac{4\pi}{\lambda^2} A_e$$

- Polarization = direction of Electric Field as a function of time:
 - straight line: linear polarization,
 - circle: circular polarization (LH or RH),
 - ellipse: elliptical polarization.

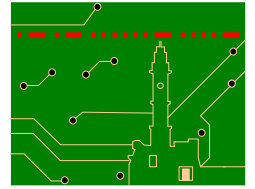
Polarization Example



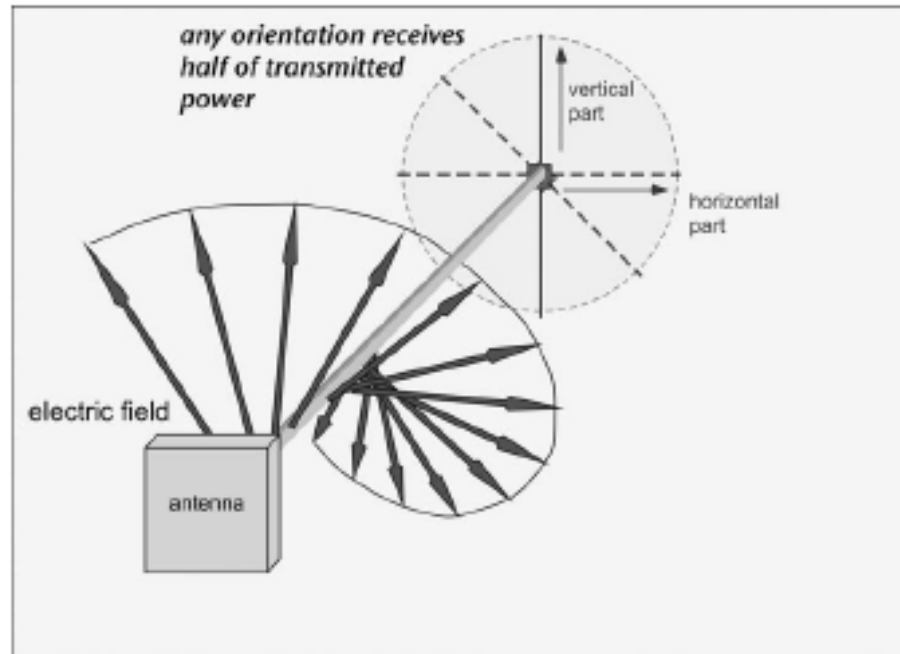
➤ linear...



➤ circular...

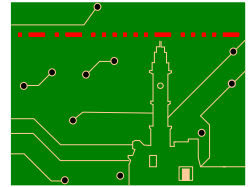
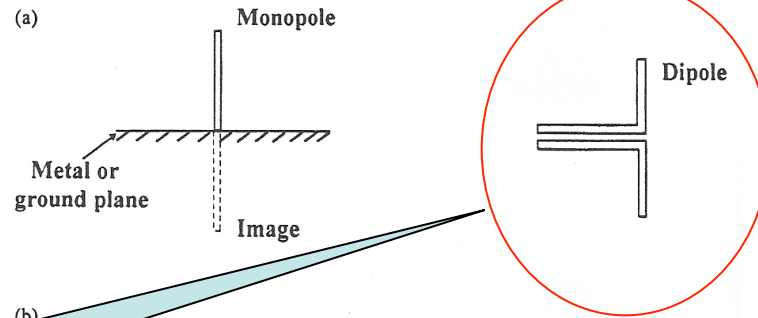


Polarization Mismatch

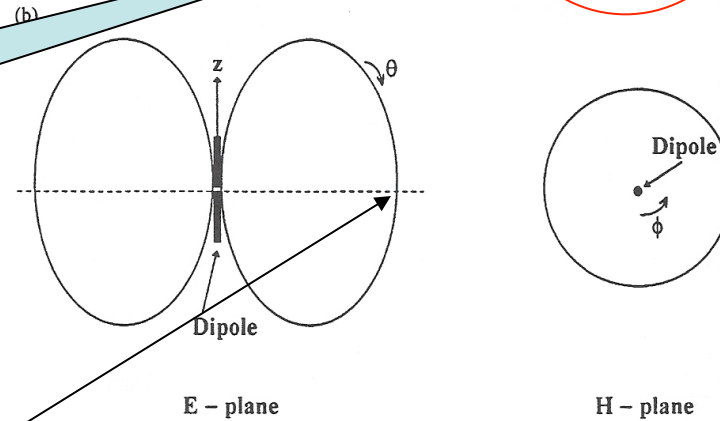


➤ reducing received power by 3-dB

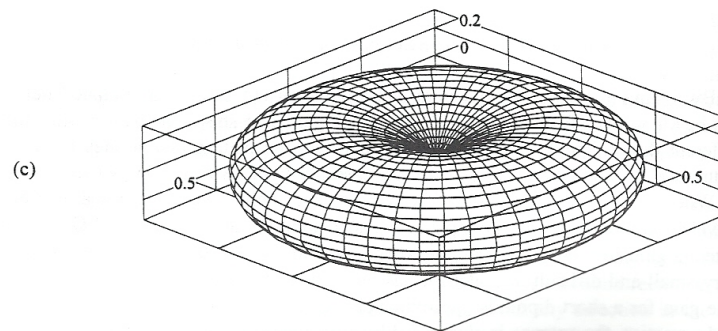
Example: Dipole



Open circuit?

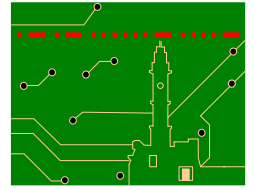


➤ $G = 1.64 \Rightarrow 2.15 \text{ dBi}$



- ERP: transmitted power referenced to dipole gain.
- EIRP: transmitted power referenced to isotropic antenna.

Βασική ερώτηση μαθήματος



RADIO NEWS FOR FEBRUARY, 1934 403

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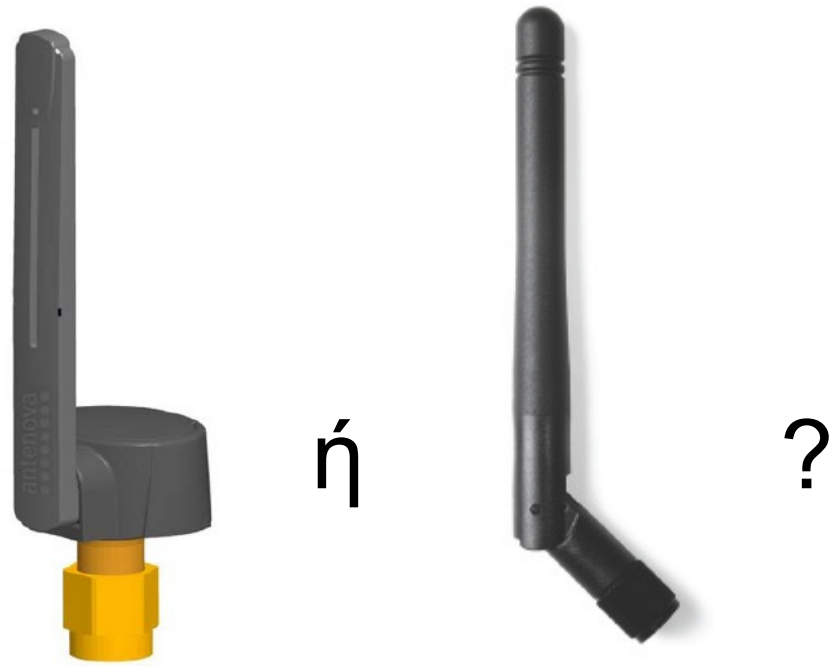
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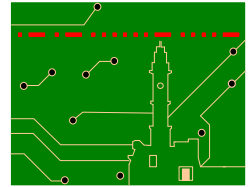
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State



Κεραίες 2.4-2.5GHz



	Typical performance
Peak gain	2.2 dBi
Average gain	-1.0 dBi
Average efficiency	80%
Maximum Return Loss	-13 dB
Maximum VSWR	1.6:1



Frequency [GHz]	Gain [dBi]	Impedance [Nom]	VSWR	Polarization	Electrical Length	Radiation
2.4 – 2.5	2.0	50 Ω	≤ 2.0	Vertical	¼, dipole	Omni

Questions?

