2011-II: Transmission Lines and Antennas

PRINTED ANTENNAS:

RECTANGULAR PATCH ANTENNA ANALYSIS AND DESIGN

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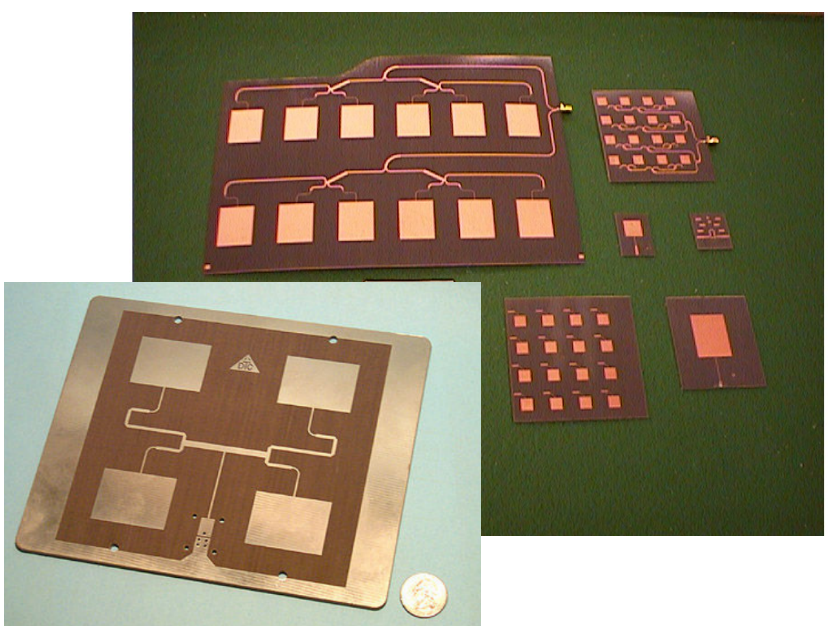
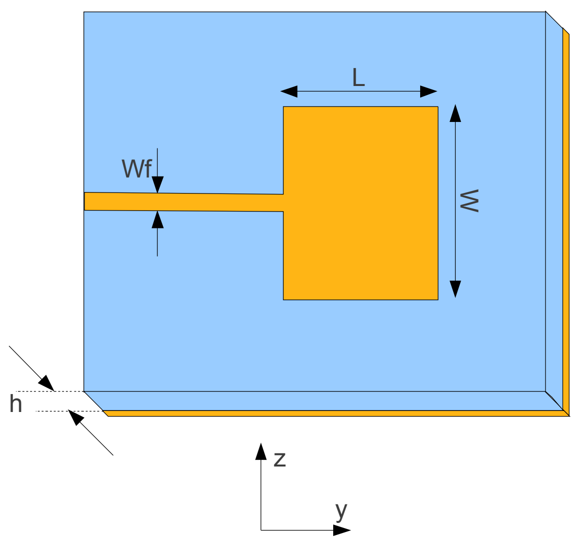
Printed Antennas

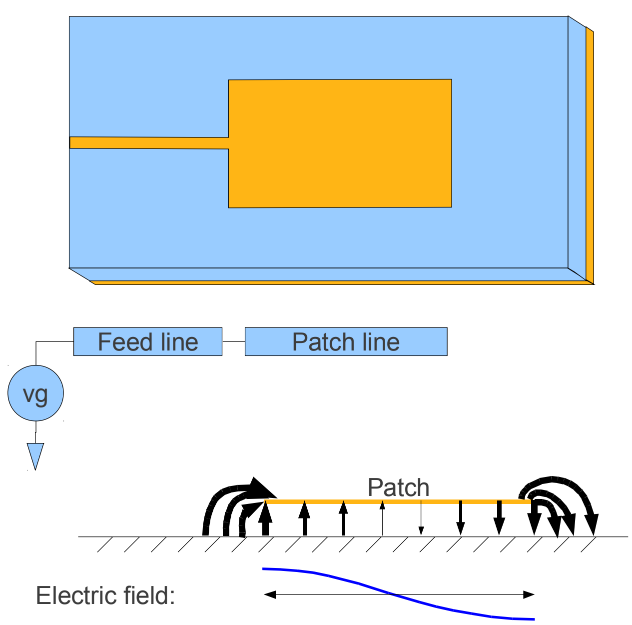


Line-fed Rectangular Patch



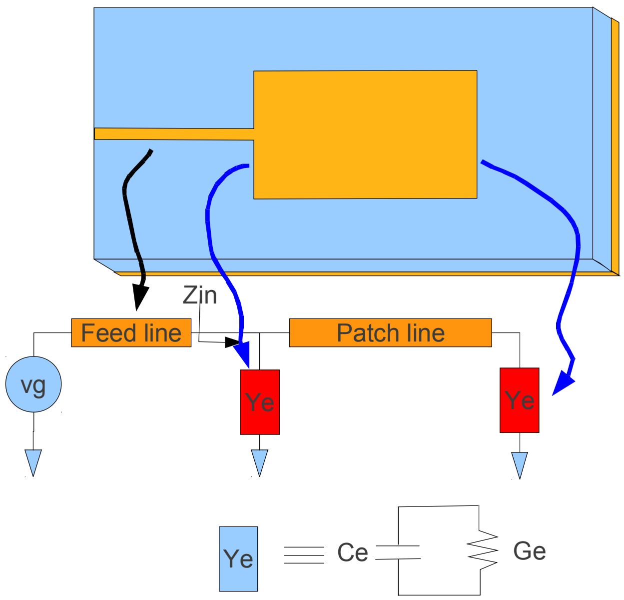
- A grounded subtrate is used as support medium, h << λ
- A normal microstrip line is used to feed the antenna (Wf << λ).
- Antenna is a very wide microstrip line (W~λ): wide, open edges allow leaking of guided wave energy into space
- A simple model and analysis will be presented

The Patch as a Transmission Line



- A simple transmission line model results in a cascade of two lossless lines → imaginary Zin.
- Strong discontinuities at patch edges cause leaking of fields (fringing fields):
  - ”Loss” (radiation)
  - Capacitive effect at edges (charge accumulation)

Accounting for discontinuities



- The effect of edges is modelled by (equal) complex admittances, conductance is due to radiation, susceptance to the capacitive effect between patch and ground plane.
- Resonance is achieved when patch Zin is purely real, i.e. admitance due to right edge is transformed by patch line into its complex conjugate $\longrightarrow$ patch line length is somewhat less than $\lambda/2$ due to capacitances (apparent enlongation).

Edge Conductance and Capacitance

- Conductance is obtained from ratio of power radiated by a ”slot” to the square modulus of voltage applied:

$$
\begin{aligned}
G_e &= \frac{2P_{rad}}{|V_0|^2} = \frac{-2+\cos(X)+XS_i(X)+\frac{\sin(X)}{X}}{120\pi^2} \\
X &= k_0 W \\
S_i(x) &= \int_0^x \frac{\sin u}{u} du
\end{aligned}
$$

- Capacitance is most conveniently expressed in terms of the apparent enlongation of the patch line using conventional microstrip formulas (real patch length must be $\lambda_g/2$ minus twice this):

$$
\frac{\Delta L}{h} = 0.412 \frac{\epsilon_{r,eff}+0.3}{\epsilon_{r,eff}-0.258} \cdot \frac{W/h+0.264}{W/h+0.8}
$$

$$
L_{patch} = \frac{\lambda_0}{2\sqrt{\epsilon_{r,eff}}} - 2\Delta L
$$

Enhancing the Model

- Computation of Ge above assumes the slot radiates in isolation. Plugging two of these into the model assumes that <u>power adds up</u>, which is not exact since superposition applies to *fields* not power: *fields radiated by these edges interfer in space,* sometimes constructively and sometimes destructively. This effect is accounted by adding a mutual conductance:

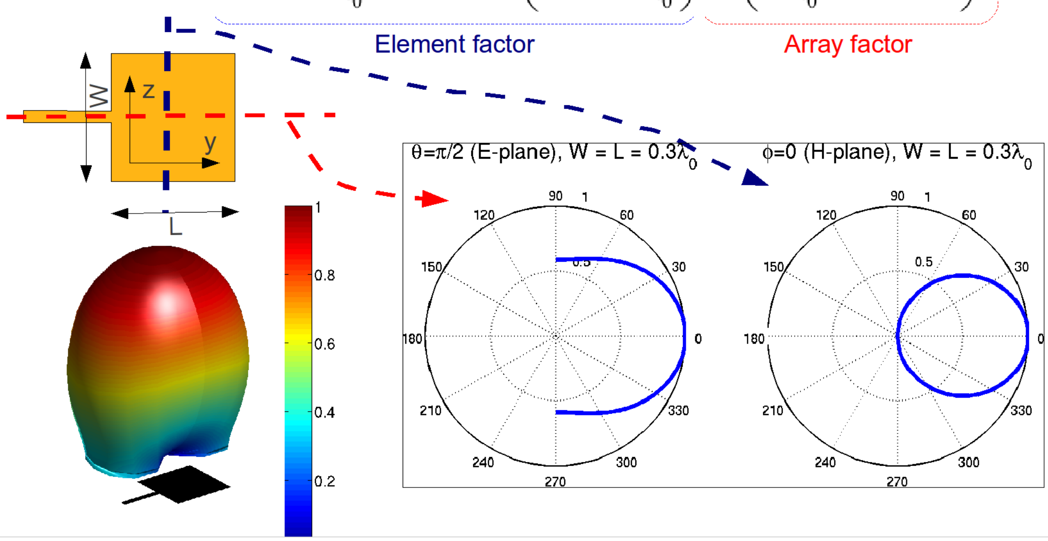
$$G_{12} = \frac{1}{120\pi^2} \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 W}{2} \cos\theta\right)}{\cos\theta} \right]^2 J_0(k_0 L \sin\theta) \sin^3\theta \, d\theta$$

- This model is valid only at resonance or close, as it assumes equi-phase excitation of the ”edge antenna elements”. Total input impedance is thus computed as follows:

$$R_{in} = \frac{1}{2\,(G_e + G_{12})}$$

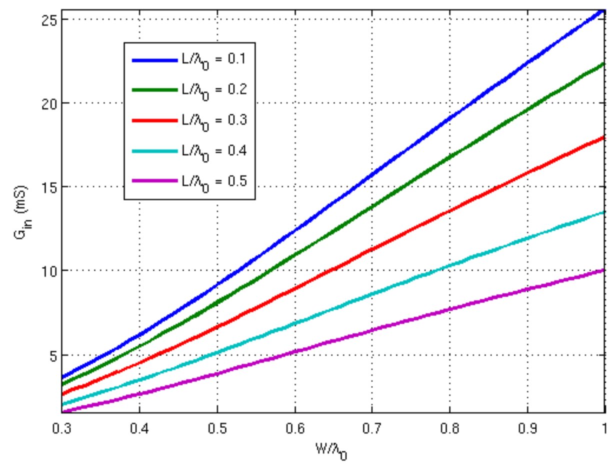
Total Antenna Radiation Pattern

$$\underline{e}(\theta,\phi) = -jV_0 \underbrace{4\pi \frac{W}{\lambda_0} \hat{\phi} \sin\theta \,\mathrm{sinc}\left(\pi \cos\theta \frac{W}{\lambda_0}\right)}_{\text{Element factor}} \underbrace{\cos\left(\pi \frac{L}{\lambda_0} \sin\theta \sin\phi\right)}_{\text{Array factor}}$$



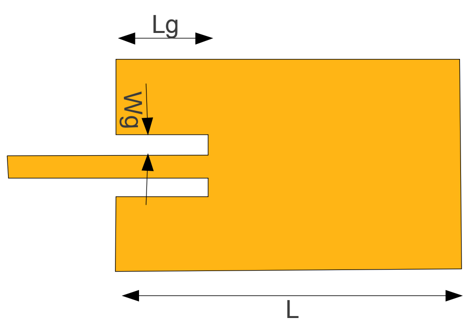
Controlling Patch Input Resistance

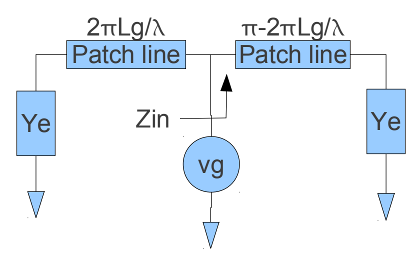
- A wider patch has lower input resistance. Sometimes 50Ω require a too wide patch!



Controlling input Resistance (2)

- By suitably modifying the feed, different V/I ratio at input terminal are obtained, thus changing input resistance → inset feed





$$R_{in}(L_g) = R_{in}(L_g = 0)\cos^2\left(\frac{L_g \pi}{L}\right)$$

- Wg is chosen so that the grounded coplanar waveguide T.L. has the same characteristic impedance as the microstrip line.

Patch Design Procedure

Usually one needs to obtain a fixed value for the patch input impedance. Two design procedures can be used:

- Set W to an ”optimum” value, then use inset feed to attain the specified impedance.
- Compute W to control input impedance.

Design with Inset Feed for small Rin (say < 150 Ohm)

- Given f, h, epsr, Zin:

1. Compute patch width using a rule of thumb value:

$$W_{opt} = \frac{1}{2}\frac{\lambda_0(f_R)}{\sqrt{\varepsilon_{average}}} \qquad \varepsilon_{average} = \frac{1}{2}(\varepsilon_r + 1)$$

2. Compute effective dielectric constant (for sure W>h) and apparent patch enlongation $\triangle$L

$$\epsilon_{r,eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2\sqrt{1 + 12\frac{h}{W}}}$$

$$\frac{\Delta L}{h} = 0.412\frac{\epsilon_{r,eff} + 0.3}{\epsilon_{r,eff} - 0.258} \cdot \frac{W/h + 0.264}{W/h + 0.8}$$

3. Compute patch length considering the above:

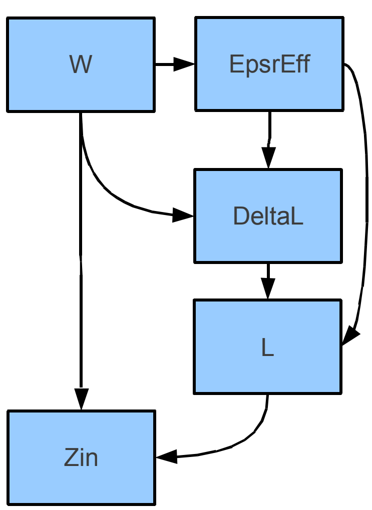
$$L = \frac{\lambda_g}{2} - 2\Delta L = \frac{c}{2f\epsilon_{ref}} - 2\Delta L$$

4. Compute resulting Rin (from curves or formulas), choose inset dimensions Lg, Wg to attain goal Rin.

Design for Rin varying W
For large Rin (say >150 Ohm)

- Choose $L/\lambda_0 \approx \frac{1}{2}\frac{1}{\sqrt{\varepsilon_r}}$
  Compute W from curves such that Zin is obtained.
- Follow steps 2-4 as in previous case.
- The resulting value for L will be slightly different from the one initially chosen...
- Iterate if necessary with the new value for L
- This manual/graphical procedure is to be avoided whenever possible: it involves tedious computations and is prone to error; furthermore, solution is inexact in view of visual interpolation being required. The preferred way is to write a program to solve exactly the non-linear equation system (see next slide).

Design for Rin varying W
(exact solution)



- The design equations for the patch can be represented in a dependence graph (left): arrows indicate the availability of an explicit equation to compute the element at the tip from all the elements where arrows originate (f, h and epsr are implicitly available for all expressions).
- This diagram shows that W is an independent variable, and ultimately one may write down an equation:

  Zin = g(W)
- This equation may thus solved using a non-linear solver (e.g. MATLAB's fzero):
- W = argmin_W|g(W) - Zspec|