Research on Improving Radiation Efficiency of Double-layer Patch Antenna

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We are stepping into a world of communication.

As one of the core components in a communication system, antennas are widely used in our daily life.
BACKGROUND

Patch antenna: Antenna with metal patch suspended over a ground plane

- Generally lightweight
- Low profile
- Easily made
- Productive at a low cost

Inherently narrow bandwidth

known improving method: using double-layer structure

(top) Radiating conductor
(Dielectric substrate
Normal case: single layer
Ground plane
Double layer case

(1)

(2)
Antenna efficiency = Radiation efficiency × [1-(reflection coefficient)$^2$]  

$$\eta_{\text{ant}} = \eta_{\text{rad}} (1-|\Gamma|^2)$$

For double layer case:
- wider bandwidth
- steep falling down in radiation efficiency $\eta_{\text{rad}}$
Generally, in order to get better antenna efficiency $\eta_{\text{ant}}$, we shall focus on two factors:

- Radiation efficiency $\eta_{\text{rad}}$
- Reflection coefficient $\Gamma$

For double layer patch antenna radiation efficiency, worse performance on radiation efficiency.
PROBLEM

How to optimize radiation efficiency $\eta_{\text{rad}}$?

Dielectric substrate parameters:

- Permittivity ($\varepsilon$)
- Dielectric loss tangent ($\delta$)
- Permeability ($\mu$, generally fixed as $\mu_0$)
- ...

So …

- What will happen when using different loss tangent ($\tan\delta$) of the substrates?
- What about changing $\varepsilon$ of the substrates?
Simulation model
- Double-layer patch antenna with center frequency around 1 GHz*.

Size of the simulation models

* Feeding based on FR4-epoxy as both upper and lower layer substrates
Two materials as substrates:

- **FR4-epoxy**:
  Relative permittivity $\varepsilon_r = 4.4$
  loss tan $\delta = 0.02$

- **Teflon**:
  Relative permittivity $\varepsilon_r = 2$
  loss tan $\delta = 0.001$

<table>
<thead>
<tr>
<th>Case</th>
<th>Upper layer</th>
<th>Lower layer</th>
<th>$\delta$ ranging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>FR4-epoxy</td>
<td>FR4-epoxy</td>
<td>$10^{-1}$ to $10^{-5}$</td>
</tr>
<tr>
<td>Case 2</td>
<td>FR4-epoxy</td>
<td>Teflon</td>
<td>$10^{-1}$ to $10^{-5}$</td>
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<tr>
<td>Case 3</td>
<td>Teflon</td>
<td>FR4-epoxy</td>
<td>$10^{-1}$ to $10^{-5}$</td>
</tr>
<tr>
<td>Case 4</td>
<td>Teflon</td>
<td>Teflon</td>
<td>$10^{-1}$ to $10^{-5}$</td>
</tr>
</tbody>
</table>
OBSERVATION AND CONCLUSIONS

- Radiation efficiency $\eta_{rad}$ of four cases look similar
Comparison between changing $\tan\delta$ of upper and lower layer

**Case 1**

- FR4-epoxy
- FR4-epoxy

**Combination of FR4/FR4**

- Dielectric loss ($\tan\delta$) — main impact factor
- Relation
- More sensitive to lower layer substrate’s dielectric loss.

![Graph](image-url)

**Graph Details**

- X-axis: loss $\tan\delta$
- Y-axis: radiation efficiency (dB)
- Solid line: changing upper layer
- Dashed line: changing lower layer
OBSERVATION AND CONCLUSIONS

Similar observations also happen in other model teams.

Case 2

\[ \text{FR4-epoxy} \rightarrow \text{Teflon} \]

Combination of FR4-epoxy/Teflon
OBSERVATION AND CONCLUSIONS

Case 3

\[ \text{Teflon} \rightarrow \text{FR4-epoxy} \]

Combination of Teflon/FR4-epoxy

\[ \text{radiation efficiency (dB)} \]

\[ \text{loss } \tan \delta \]
OBSERVATION AND CONCLUSIONS

Based on observations and corresponding conclusions demonstrated, we get some hints on optimizing radiation efficiency of the antenna.

Case 4

- Teflon
- Teflon

Combination of Teflon/Teflon

- Combination of Teflon/Teflon
CONCLUSIONS AND FUTURE WORK

- The relation between the loss tanδ and radiation efficiency $\eta_{\text{rad}}$ is that when tanδ increases, $\eta_{\text{rad}}$ decreases.
- The radiation efficiency seems more sensitive towards the changing of lower layer substrate’s loss tangent.
- When designing a double layer patch antenna, try to decrease the loss tan δ, especially of lower layer substrate, within price requirement.

Future work

- Reason of radiation efficiency falling down at some frequency ranges is not yet of certainty, which needs more research on it.
- Reducing reflection coefficient at frequency of high radiation efficiency.
THANK YOU FOR LISTENING!
ANNEX: ELECTRIC FIELD DISTRIBUTION

FR4(upper)/FR4(lower) model

0.9GHz

0.95GHz
ANNEX: ELECTRIC FIELD DISTRIBUTION

FR4(upper)/Teflon(lower) model

0.9GHz

0.95GHz
ANNEX: ELECTRIC FIELD DISTRIBUTION

Teflon(upper)/FR4(lower) model

1.3GHz

1.35GHz
ANNEX: ELECTRIC FIELD DISTRIBUTION

Teflon(upper)/Teflon(lower) model

1.3GHz

1.35GHz