Development of Dielectric Resonator Antenna (DRA)

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Outline

I. Introduction

II. Circularly Polarized DRA Using a Parasitic Strip

III. Frequency Tuning Technique

IV. Omnidirectional Circularly Polarized DRAs

V. Dualband & Wideband DRAs

VI. Dualfunction DRAs
The DRA is an antenna that makes use of a radiating mode of a dielectric resonator (DR).

It is a 3-dimensional device of any shape, e.g., hemispherical, cylindrical, rectangular, triangular, etc.

Resonance frequency determined by the its dimensions and dielectric constant $\varepsilon_r$. 

What is Dielectric Resonator Antenna (DRA)?
Some DRAs:
Advantages of the DRA

- Low cost
- Low loss (no conductor loss)
- Small size and light weight
- Reasonable bandwidth (~10% for \( \varepsilon_r \sim 10 \))
- Easy of excitation
- High radiation efficiency (generally > 95%)
Excitation schemes

(i) Microstrip line feed
Excitation schemes

(ii) Aperture-couple feed
Excitation schemes

(iii) Coaxial feed
Coaxial feed

Top view

Bottom view
Aperture-coupled feed

Bottom view

Top view
Corporate feedline for DRA array

Slot-fed DRA array using corporate microstrip feed network
Conformal-Strip Method

Hemispherical DRA

Conducting conformal strip

Ground plane
Rectangular Dielectric Resonator Antennas
Proposed Antenna Geometry

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<tbody>
<tr>
<td>a (mm)</td>
<td>b (mm)</td>
<td>d (mm)</td>
<td>l₁ (mm)</td>
<td>W₁ (mm)</td>
<td>εᵣ</td>
</tr>
<tr>
<td>14.3</td>
<td>25.4</td>
<td>26.1</td>
<td>10</td>
<td>1</td>
<td>9.8</td>
</tr>
</tbody>
</table>
Resonant frequency of TE\(_{mnl}(y)\) mode

\[ f_0 = \frac{c}{2\pi\sqrt{\varepsilon_r}} \sqrt{k_x^2 + k_y^2 + k_z^2} \]

\[ k_x = \frac{m\pi}{a}, \quad k_y = \frac{n\pi}{b}, \quad k_z = \frac{l\pi}{2d} \]

\[ k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \]
Numerical Solution

- Finite-Difference Time-Domain (FDTD) method

Advantages

- Very simple
- High modeling capability for general EM structures
- No spurious modes nor large matrix manipulation
- Provide a very wideband frequency response

Disadvantages

- Time consuming, powerful computer required
Baseband Gaussian pulse

\[ E_z = \exp\left[ -\left( \Delta t \cdot n - 3T \right)^2 / T^2 \right] \]

T : pulse width

\[ Z_{in} = \frac{FFT[V(t)]}{FFT[I(t)]} \]

\[ S_{11} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \]

Source occupies only one grid
Uniform Cartesian grids

\[ \Delta x = 0.715 \text{ mm}, \Delta y = 0.508 \text{ mm}, \Delta z = 0.5 \text{ mm} \]

\[ T = 0.083\text{ns}, t_0 = 3T \]

10-cell-thick PML with polynomial spatial scaling
\( (m = 4 \text{ and } \kappa_{\text{max}} = 1) \)

total grid size : 80\( \Delta x \) 110\( \Delta y \) 112\( \Delta z \)

total time steps : 10000
• Reasonable agreement.
• Wide Bandwidth of ~ 43%.
• Dual resonant $\text{TE}_{111}^y$ and $\text{TE}_{113}^y$ modes are excited.
### Comparison between Theory and Measurement

<table>
<thead>
<tr>
<th>Resonant Modes</th>
<th>Measured resonant frequencies</th>
<th>Calculated resonant frequencies (FDTD)</th>
<th>Predicted resonant frequencies (DWM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$f_{\text{mea}}$ (GHz)</td>
<td>$f_{\text{FDTD}}$ (GHz)</td>
<td>error (%)</td>
</tr>
<tr>
<td>TE$_{111}^y$</td>
<td>3.81</td>
<td>3.90</td>
<td>2.3</td>
</tr>
<tr>
<td>TE$_{112}^y$</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>TE$_{113}^y$</td>
<td>4.57</td>
<td>4.60</td>
<td>0.7</td>
</tr>
</tbody>
</table>

- *Reasonable agreement.*
Field Distribution --- $\text{TE}_{111}^y$

Imaged DRA (ground plane removed)

With ground plane
Field Distribution --- $TE_{112}^y$

Imaged DRA (ground plane removed)
Field Distribution --- TE$_{113}^y$

Imaged DRA (ground plane removed)

With ground plane
Radiation Patterns

- Broadside radiation patterns are observed.
- Measured E-plane crosspolarized fields mainly caused by finite ground plane diffraction.

\[ f = 3.5 \text{ GHz} \]

\[ f = 4.3 \text{ GHz} \]
III. Circularly Polarized Design using a Parasitic Strip
### Proposed Antenna Geometry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>24 (mm)</td>
</tr>
<tr>
<td>$b$</td>
<td>23.5 (mm)</td>
</tr>
<tr>
<td>$d$</td>
<td>12.34 (mm)</td>
</tr>
<tr>
<td>$l_1$</td>
<td>10 (mm)</td>
</tr>
<tr>
<td>$W_1$</td>
<td>1 (mm)</td>
</tr>
<tr>
<td>$l_2$</td>
<td>12 (mm)</td>
</tr>
<tr>
<td>$W_2$</td>
<td>1 (mm)</td>
</tr>
<tr>
<td>$\phi_0$</td>
<td>225.6 (degree)</td>
</tr>
<tr>
<td>$\varepsilon_r$</td>
<td>9.5</td>
</tr>
</tbody>
</table>
• Reasonable agreement.
• Bandwidth ~ 14%.
• Two nearly-degenerate $TE_{111}(y)$ modes are excited.
⇒ CP operation
Axial Ratio in the boresight direction

3-dB AR bandwidth is ~ 2.7%, which is a typical value for a singly-fed CP DRA.
The H field of the DRA without and with parasitic strip (Top view)

Without parasitic strip - LP field

With parasitic strip - CP field

3.4 GHz
Radiation Patterns ($f = 3.4\text{GHz}$)

- A broadside radiation mode is observed.
- For each radiation plane, the LHCP field is more than 20dB stronger than the RHCP field.
- The maximum gain is $5.7 \text{ dBic}$ (not shown here).
Effects of feeding strip length $l_1$

- Input impedance changes substantially with $l_1$.
- AR is almost unchanged for different $l_1$.
- $l_1$ can be adjusted to match the impedance without changing AR.
II. Frequency Tuning Technique
The DRA for a particular frequency may not be available from the commercial market.

Fabrication tolerances cause errors between measured and calculated resonant frequencies.

Frequency tuning methods:
(i) loading-disk; and
(ii) parasitic slot.
Frequency Tuning Technique
- using a loading disk
The slot-coupled DRA with a conducting loading cap

- **Hemispherical DRA**: radius $a = 12.5$ mm, dielectric constant $\varepsilon_r = 9.5$.
- **Coupling slot**: length $L_s$, width $W_s$
- **Open-circuit stub**: length $L_t$
- **Grounded dielectric slab**: $\varepsilon_{rs} = 2.33$, height $d = 1.57$ mm
- **Microstrip feedline**: width $W_f = 4.7$ mm
Calculated and measured return losses 
\((L_s = 12 \text{ mm and } W_s = 1 \text{ mm})\)

**Resonance frequency:**
- 3.52 GHz without any conducting cap \((\alpha = 0^0)\), with \(L_t = 4.42 \text{ mm}\)
- 3.25 GHz \((\alpha = 26.38^0 \text{ and } L_t = 4.42 \text{ mm})\)
- 3.68 GHz \((\alpha = 52.8^0 \text{ and } L_t = 13.6 \text{ mm})\)
Calculated and measured radiation patterns

- Reasonable agreement between theory and experiment.
- The effect of loading cap on field pattern is not significant.

3.25 GHz ($\alpha = 26.38^\circ$ and $L_t = 4.42$ mm)

3.58 GHz ($\alpha = 52.8^\circ$ and $L_t = 13.6$ mm)
Calculated $\alpha$ and $L_t$ for having a good return loss (minimum $|S_{11}| < -20$dB)

The resonant frequency can be tuned by varying $\alpha$ and $L_t$

- $\alpha$ decreases from 26.38° to 0° ($3.25 < f_r < 3.5$ GHz)
- $\alpha$ increases from 0° to 52.8° ($3.5 < f_r < 3.78$ GHz)
The bandwidth decreases after a loading cap is added.
Frequency Tuning Technique
- using a parasitic slot
The annular-slot-excited cavity-backed DRA

(a) Side view

(b) Top view
IV. **Omnidirectional Circularly Polarized DRA**
Advantages of omnidirectional CP antenna

- Provide larger coverage.

CP DRAs concentrated on broadside-mode designs only.
Design I:

Slotted omnidirectional CP DRA
Dielectric cube with oblique slots (polarizer) fabricated on its four sidewalls.

Centrally fed by a coaxial probe extended from a SMA connector, whose flange used as the small ground plane.
Antenna principle

LP omnidirectional DRA

Dielectric block with the wave polarizer

Proposed compact omnidirectional CP DRA
Prototype for 2.4 GHz WLAN design

**Photographs of the prototype**

Top face and sidewalls

Bottom face

**Design parameters**

\[ \varepsilon_r = 15, \ a = b = 39.4 \text{ mm}, \ h = 33.4 \text{ mm}, \ w = 9.4 \text{ mm}, \ d = 14.4 \text{ mm}, \ r_1 = 0.63 \text{ mm}, \ l = 12.4 \text{ mm}, \ g = 12.7 \text{ mm} \]
Simulated and measured results

**Reflection coefficient**

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Simulated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20.3% (2.34-2.87 GHz)</td>
<td>24.4% (2.30-2.94 GHz)</td>
</tr>
</tbody>
</table>

**Axial ratio**

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Simulated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8.2% (2.34-2.54 GHz)</td>
<td>7.3% (2.39-2.57 GHz)</td>
</tr>
</tbody>
</table>
- Very good omnidirectional characteristic
- In the horizontal plane, LHCP fields > RHCP fields by ~20 dB.
Simulated and measured antenna gain

Simulated and measured antenna gain

Gain (dBic)

Frequency (GHz)

HFSS Simulation

Experiment
Design II:

Wideband omnidirectional CP antenna with parasitic metallic strips
Antenna configurations

- Four parasitic metallic strips are embedded in the lateral slots to enhance the AR bandwidth.
- The hollow circular cylinder is introduced to enhance the impedance bandwidth.
Photographs of the prototype

Prototype for 3.4 GHz WiMAX design

Top face and sidewalls

Bottom face

Design parameters

$\varepsilon_r = 15, a = b = 30 \text{ mm}, h = 25 \text{ mm}, r = 3 \text{ mm}, w = 7 \text{ mm}, d = 10.5 \text{ mm}$

$l_s = 30.5 \text{ mm}, w_s = 1 \text{ mm}, x_0 = 6.4 \text{ mm}, r_1 = 0.63 \text{ mm}, l = 19 \text{ mm}.$
Simulated and measured reflection coefficient and axial ratio

Impedance bandwidth:
Simulated: 22.3% (3.11-3.89 GHz)
Measured: 24.5% (3.08-3.94 GHz)

AR bandwidth:
Simulated: 24.8% (3.11-3.99 GHz)
Measured: 25.4% (3.16-4.08 GHz)

Overlapping bandwidth: 22.0%; bandwidth widened by ~3 times.
Simulated and measured results

Antenna gain

- Measured gain: wider bandwidth.
- Measured antenna efficiency: 84-98% (3.1-3.9 GHz).
Simulated and measured radiation patterns

- LHCP fields > RHCP fields by more than 15 dB in horizontal plane.
- Stable radiation patterns across the entire passband (3.1 – 3.9 GHz).
V. Dualband & Wideband DRAs
(i) Rectangular DRA
Dualband and wideband antennas are extensively used (e.g., WLAN)

Multi-element DRA [1]
- requiring more DR elements and space

Hybrid slot-DRA [2]
- coupling slot used as the feed and antenna
- inflexible in matching the impedance

Use of higher-order DRA

• Wideband DRA [1]

• Dualband DRA [2]

• Trial-and-error approach is normally used

• Systematic design approach is desirable


The E-field should vanish on the PEC and the TE_{112} mode cannot be excited properly.

The TE_{111} mode and TE_{113} mode are used in the dual-mode design.
The wavenumbers $k_{x1}, x_2$ and $k_{z1}, z_2$ can be written as follows:

$$k_{z2} = \frac{3\pi}{2d}$$
$$k_{z1} = \frac{\pi}{2d}$$
$$k_{x1} = k_{x2} = \frac{\pi}{a}$$
From the DWM model, the frequencies $f_1, f_2$ are given by:

$$f_{1,2} = \frac{c}{2\pi \sqrt{\varepsilon_r}} \sqrt{k_{x_1,x_2}^2 + k_{y_1,y_2}^2 + k_{z_1,z_2}^2}$$

where

$$k_{y_1,y_2} = \sqrt{k_{1,2}^2 - k_{x_1,x_2}^2 - k_{z_1,z_2}^2} \quad (*)$$

in which $k_{1,2} = 2\pi \sqrt{\varepsilon_r} f_{1,2} / c$ are wavenumbers in the dielectric, with $c$ being the speed of light in vacuum.
Engineering Formulas for the DRA dimensions

\[ a = \frac{10.32}{\sqrt{9k_1^2 - k_2^2}} + 10.32^{-(3.96-f_2/f_1)} \]

\[ d = \pi \sqrt{\frac{2}{k_2^2 - k_1^2}} + \Delta d \]

\[ b = 0.65b_1 + 0.35b_2 \]

where

\[ \Delta d = \left[ 0.1393 \left( \frac{f_2}{f_1} \right)^4 - 2.3209 \left( \frac{f_2}{f_1} \right)^3 + 11.4422 \left( \frac{f_2}{f_1} \right)^2 - 23.4984 \left( \frac{f_2}{f_1} \right) + 18.4437 \right] \times 10^{-3} \text{ (m)} \]

\[ b_{1,2} = \frac{2}{k_{y1,y2}} \tan^{-1} \sqrt{\left( 1 - \frac{1}{e_r} \right) \left( \frac{k_{1,2}}{k_{y1,y2}} \right)^2 - 1} \]
Limit of frequency ratio $f_2/f_1$

From

$$a = \frac{10.32}{\sqrt{9k_1^2 - k_2^2}} + 10.32 - (3.96 - \frac{f_2}{f_1})$$

We have

$$9k_1^2 - k_2^2 d \geq 0 \quad \Rightarrow \quad 3k_1 > k_2 \quad \text{or} \quad 3f_1 > f_2$$

giving

$$f_2/f_1 < 3$$

which is the theoretical limit that is not known before.
Compared with DWM results, errors of $f_1$, $f_2$ are both less than 2.5% for $1 < f_2/f_1 \leq 2.8$, $5 \leq \varepsilon_r \leq 70$. 

$f_1$ kept constant at 2.4 GHz.
A. Example for Dual-band Rectangular DRA Design

Given: \( f_1 = 3.47 \text{ GHz (WiMAX)} \)
\[
\begin{align*}
f_2 & = 5.2 \text{ GHz (WLAN)}, \quad \varepsilon_r = 10
\end{align*}
\]

Using dual-mode formulas

\( a = 20.8 \text{ mm}, \quad b = 10.5 \text{ mm}, \quad \text{and} \quad d = 18.5 \text{ mm}. \)
Configuration of the dualband DRA

\[ W = 2.6 \text{ mm}, \ L = 10.6 \text{ mm}, \ L_s = 7.2 \text{ mm}, \ W_f = 1.94 \text{ mm}, \ \ h = 0.762 \text{ mm}, \ \varepsilon_{rs} = 2.93 \]
Measured and simulated reflection coefficients

Measured bandwidths:
Lower band: 15% (3.25-3.78 GHz) covering WiMAX (3.4-3.7 GHz).
Upper band: 8.3% (5.03-5.47 GHz) covering WLAN (5.15-5.35 GHz).
### Comparison of Design, Simulated, and Measured Resonance Frequencies of TE_{111}^y and TE_{113}^y Modes

<table>
<thead>
<tr>
<th>Resonant Mode</th>
<th>Measured frequency (GHz)</th>
<th>Design frequency</th>
<th>Simulated HFSS frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( f_{1,2} ) (GHz)</td>
<td>Error (%)</td>
</tr>
<tr>
<td>TE_{111}^y</td>
<td>3.40</td>
<td>3.47</td>
<td>2.05</td>
</tr>
<tr>
<td>TE_{113}^y</td>
<td>5.18</td>
<td>5.30</td>
<td>2.32</td>
</tr>
</tbody>
</table>
- TE$_{111}^y$ mode: measured (3.40 GHz), simulated (3.47 GHz).
- Broadside radiation patterns are observed for both planes.
- Co-polarized fields > cross-polarized fields by more than 20 dB in the boresight direction.
- $\text{TE}_{113}^y$ mode: measured (5.18 GHz), simulated (5.24 GHz).
- Broadside radiation patterns are observed for both planes.
- Co-polarized fields $>$ cross-polarized fields by more than 20 dB in the boresight direction.
- **TE_{111}^y** mode: Maximum gain of 4.02 dBi at 3.48 GHz.
- **TE_{113}^y** mode: Maximum gain of 7.52 dBi at 5.13 GHz.
- Electrically larger antenna has a higher antenna gain.
B. Example for Wideband DRA Design

Given: \( f_1 = 1.98 \text{ GHz (PCS)} \)
\[ f_2 = 2.48 \text{ GHz (WLAN)}, \ \varepsilon_r = 10 \]

Using formulas for dual-mode rectangular DRA

\[ a = 30.7 \text{ mm}, \ b = 24.7 \text{ mm}, \ \text{and} \ d = 47.7 \text{ mm}. \]
Configuration of the wideband DRA

$l = 17$ mm, $W = 1$ mm
Measured and simulated reflection coefficients

**Measured bandwidths**: 30.9% (1.83-2.50 GHz)  
PCS (1.85-1.99 GHz), UMTS (1.99-2.20 GHz)  
& WLAN (2.4-2.48 GHz)
Measured and simulated radiation patterns

- Measured (2.16 GHz), simulated (2.11 GHz).
- Broadside radiation patterns are observed.
- Co-polarized fields > cross-polarized fields by more than 20 dB in the boresight direction.
Measured and simulated radiation patterns

- Measured (2.41 GHz), simulated (2.46 GHz).
- Broadside radiation patterns are observed.
- Co-polarized fields > cross-polarized fields by more than 20 dB in the boresight direction.
• The maximum gain of 6.98 dBi at 2.47GHz.
• $\text{TE}_{113}^y$ -mode gain $>$ $\text{TE}_{111}^y$ -mode gain.
(ii) Cylindrical DRA
Resonance frequency of the $\text{HEM}_{mnr} \ mode$ of the cylindrical DRA

\[ k_{\rho i}^2 + k_{zi}^2 = \varepsilon_r k_{0i}^2 \quad (1) \]

\( i = 1, 2 \) for \( f_1, f_2 \)

- \( f_1 : \text{HEM}_{111} \) mode frequency
- \( f_2 : \text{HEM}_{113} \) mode frequency

- \( k_{\rho i} \) & \( k_{zi} \): dielectric wavenumbers along the \( \rho \) & \( z \) directions

- \( k_{0i} = 2\pi f_i / c \): wavenumber in air
Resonance frequency of the HEM\textsubscript{mnr} mode of the cylindrical DRA

For \( k_\rho \):

\[
\frac{1}{k_\rho} \frac{J_m'(k_\rho a)}{J_m(k_\rho a)} + \frac{1}{k_\rho'} \frac{K_m'(k_\rho' a)}{K_m(k_\rho' a)} \left( \frac{\varepsilon_r J_m'(k_\rho a)}{J_m(k_\rho a)} + \frac{1}{k_\rho'} \frac{K_m'(k_\rho' a)}{K_m(k_\rho' a)} \right) = \frac{m^2 (k_\rho^2 + k_\rho'^2) (k_\rho^2 + \varepsilon_r k_\rho'^2)}{(k_\rho k_\rho')^4 a^2}
\]

(2)

where

\[
k_{\rho i}' = \sqrt{(\varepsilon_r - 1) k_{0i}^2 - k_{\rho i}^2}
\]

(3)

is the radial wavenumber outside the dielectric rod

\( J_m(x) \): Bessel function of the first kind

\( K_m(x) \): modified Bessel function of the second kind.

---

Resonance frequency of cylindrical DRA

For $k_z$: approximated by the TM$_{01}$-mode wavenumber

$$\frac{hk_z}{p_i} = \tan^{-1}\left(\frac{\varepsilon_r \sqrt{(\varepsilon_r - 1)k_0^2 - k_z^2}}{k_z}\right)$$

(i = 1, 2 for $f_1, f_2$) \hspace{1cm} (4)

where $p_1 = 1$ and $p_2 = 3$
correspond to the HEM$_{111}$ and HEM$_{113}$ modes, respectively.

Design formula of ratio $h/a$ for given $f_1, f_2,$ and $\varepsilon_r$

$f_1$: HEM$_{111}$ mode frequency (lower band)

$f_2$: HEM$_{113}$ mode frequency (upper band)

Using the covariance matrix adaptation evolutionary strategy again,

\[
\frac{h}{a} = \frac{E_S}{\varepsilon_r^4} + \sum_{i=1}^{4} \frac{1}{\varepsilon_r^{4-i}} \left( \frac{A_i}{B_i f_2} + D_i \right) + C_i
\]

\[ (1) \]

\[
\begin{bmatrix}
A_1 & B_1 & C_1 & D_1 & E_s \\
A_2 & B_2 & C_2 & D_2 & 0 \\
A_3 & B_3 & C_3 & D_3 & 0 \\
A_4 & B_4 & C_4 & D_4 & 0
\end{bmatrix} = \begin{bmatrix}
489.7 & 0.234 & -0.937 & -34800 & 116500 \\
680.3 & -625.2 & -4.402 & 3682.7 & 0 \\
36.15 & 1.511 & -4.713 & -160.2 & 0 \\
19.23 & 1.162 & 3.982 & 1.996 & 0
\end{bmatrix}
\]
Design formula of radius $a$

Radius $a$ can be found by inserting $h/a$ into (2) below:

$$a = \frac{c}{2\pi \sqrt{\varepsilon_r f_1}} \left[ \frac{E_s}{\varepsilon_r} + \sum_{i=1}^{4} \frac{1}{\varepsilon_r^{4-i}} \left( \frac{A_i}{B_i e^{a h}} + D_i \right) \right]$$

(2)

$$\begin{bmatrix} A_1 & B_1 & C_1 & D_1 & E_x \\ A_2 & B_2 & C_2 & D_2 & 0 \\ A_3 & B_3 & C_3 & D_3 & 0 \\ A_4 & B_4 & C_4 & D_4 & 0 \end{bmatrix} = \begin{bmatrix} 1.109 & -1.751 & 0.00152 & 3107.8 & -10932 \\ -0.0571 & -0.005 & -0.9973 & -304.1 & 0 \\ 0.152 & 0.0368 & -0.9764 & 17.814 & 0 \\ 4.429 & 5.659 & 6.114 & 0.057 & 0 \end{bmatrix}$$

After $a$ is found, $h$ can be determined from $h/a$.

**Maximum error of $a$:** 2.1% for $1 \leq h/a \leq 3.5$, $9 \leq \varepsilon_r \leq 27$

**Maximum error of $h$:** 3.0% for $1.28 \leq h/a \leq 1.85$, $9 \leq \varepsilon_r \leq 27$
A. Example for dualband cylindrical DRA design

Given: $f_1 = 1.71$ GHz (DCS: 1.71 - 1.88 GHz)

$f_2 = 2.4$ GHz (WLAN: 2.4 - 2.48 GHz),

$\varepsilon_r = 9.4$

Using formulas (1) & (2)

$a = 17.9$ mm & $h = 42.5$ mm
Configuration of the dualband LP DRA

Top view

Side view

\[ a = 18.7 \text{ mm}, \ h = 42.5 \text{ mm}, \ \epsilon_r = 9.4, \ l = 12.5 \text{ mm}, \ w = 1 \text{ mm}, \ \]
\[ L_s = 20 \text{ mm}, \ W_s = 1.5 \text{ mm}, \ \text{and} \ D_s = 12.75 \text{ mm}. \]

- Radius \( a \) has been slightly increased to reduce the merging effect.
Measured and Simulated Reflection coefficients

- Reasonable agreement
- Lower band impedance bandwidth: 15.5% (1.70-2.00 GHz)
- Upper band impedance bandwidth: 3.7% (2.39-2.48 GHz)
Measured and simulated radiation patterns

HEM_{111} mode: measured (1.8 GHz), simulated (1.8 GHz)
HEM_{113} mode: measured (2.42 GHz), simulated (2.45 GHz)

- Broadside radiation patterns are observed.
- Co-polarized fields > cross-polarized fields by more than 20 dB in the boresight direction.
**Measured and simulated gain**

- **HEM$_{111}$** mode: Maximum measured gain of ~6 dBi (1.75 GHz)
- **HEM$_{113}$** mode: Maximum measured gain of ~8 dBi (2.43 GHz)
Dualband CP DRA

\[ a = 18.7 \text{ mm}, \ h = 42.5 \text{ mm}, \ \varepsilon_r = 9.4, \ l = 12.5 \text{ mm}, \ w = 1 \text{ mm}, \ L_s = 21 \text{ mm}, \ W_s = 1.5 \text{ mm}, \ D_s = 12.75 \text{ mm}, \ L_1 = 26.9 \text{ mm}, \ L_2 = 26.5 \text{ mm}, \ L_3 = 56.65 \text{ mm}, \ W_0 = 4.66 \text{ mm}, \ W_1 = 7.3 \text{ mm}, \ W_2 = 4.44 \text{ mm}, \ \text{and} \ W_3 = 0.46 \text{ mm}. \]
Reasonable agreement
Lower band bandwidth: 18.9% (1.58-1.91 GHz).
Upper band bandwidth: 7.8% (2.33-2.52 GHz).
Measured and simulated axial ratios (ARs)

- Reasonable agreement
- Lower band AR bandwidth: 12.4% (1.67-1.89 GHz)
- Upper band AR bandwidth: 7.4% (2.34-2.52 GHz)
Measured and simulated radiation patterns

HEM_{111} mode: measured (1.8 GHz), simulated (1.8 GHz)
HEM_{113} mode: measured (2.42 GHz), simulated (2.45 GHz)

- Broadside radiation patterns are observed.
- LHCP fields > RHCP fields by ~20 dB in the boresight direction.
B. Example for wideband cylindrical DRA design

Given: \( f_1 = 2.90 \text{ GHz}, f_2 = 3.72 \text{ GHz}, \varepsilon_r = 9.4 \)

Using formula (5) & (6)

\[ a = 10.3 \text{ mm} \& h = 34.3 \text{ mm} \]
Configuration

\[ a = 10.3 \text{ mm}, \quad h = 34.3 \text{ mm}, \quad \varepsilon_r = 9.4, \]
\[ l = 12 \text{ mm}, \quad \text{and} \quad w = 1 \text{ mm}. \]

Good agreement

Measured impedance bandwidth: 23.5\% (3-3.8 GHz)
**Measured and simulated gain**

- **HEM\(_{111}\)** mode: Maximum measured gain of \(~7\) dBi (3.29 GHz)
- **HEM\(_{113}\)** mode: Maximum measured gain of \(~10\) dBi (3.83 GHz)
Wideband CP cylindrical DRA

Top view

Side view

\[ a = 10.3 \text{ mm}, \quad h = 34.3 \text{ mm}, \quad \varepsilon_r = 9.4, \quad l = 11.5 \text{ mm}, \quad w = 1 \text{ mm}, \]
\[ L_1 = 14.67 \text{ mm}, \quad W_0 = 1.94 \text{ mm}, \quad \text{and} \quad W_1 = 3.21 \text{ mm}. \]
Wideband CP DRA

Reflection coefficient

Axial ratio

Measured impedance bandwidth: 25.5% (3.04-3.93 GHz).

Measured 3-dB AR bandwidth: 24.7% (3.05-3.91 GHz).
VI. Dualfunction DRAs
Advantage

System size and cost can be reduced by using dualfunction DRAs.

Additional functions

- Packaging cover
- Oscillator
Packaging Cover
Conventional

Proposal

Front view
Antenna Configuration

Resonant frequency
\[ f_0 = 2.4\text{GHz} \]

Parameters:
- Hollow DRA:
  \[ L=30\text{mm}, \ W=29\text{mm}, \ H=15\text{mm}, \ & \ \varepsilon_r =12 \]

- Metallic Cavity:
  \[ a = 15\text{mm}, \ b = 21.6\text{mm}, \ h = 5\text{mm} \]
Top face : Duroid \( \varepsilon_r =2.94 \)
  thickness 0.762mm
Aperture: 0.2063 \( \lambda_e \)
Design Procedure (Simulation):

**Step 1**
Use the DWM to design a solid rectangular DRA at 2.4-GHz fundamental TE_{111} Mode.

**Step 2**
Remove the lower center portion concentrically to form a notched DRA. As a result, the resonant frequency >2.4GHz

**Step 3**
Cover the two sides with the same material. Move the frequency back to 2.4GHz by increasing the thickness. (thickness ↑ $\rightarrow f_0$ ↓ )
Experimental Verification:

- Hard-clad foam ($\varepsilon_r \approx 1$) is used to form the container.

- ECCOSTOCK HiK Powder of $\varepsilon_r = 12$ is used as the dielectric material.
Return Loss and Input Impedance
(Passive hollow RDRA with a metallic cavity)

• Good agreement.
• Bandwidth ~ 5.6%.
• Measured resonance frequency: 2.42GHz (error < 0.83%)
Radiation Patterns
(Passive hollow DRA with a metallic cavity)

- Broadside $\text{TE}_{111}^y$ mode is observed.
- Co-polarized fields generally stronger than the cross-polarized fields by 20dB in the boresight direction.
Return Loss of the Active Integrated Antenna

- Integrated with Agilent AG302-86 low noise amplifier (LNA)
  (gain of 13.6dB at 2.4GHz)
- LNA prematched to 50Ω at the input.
- A small hole is drilled on the ground plane to supply the DC bias to the LNA.
Compared to the passive DRA, the active DRA has a gain of 7 - 12dB across the observation angle from -90° to 90°. The gain is less than the specification due to unavoidable impedance variations and imperfections in the measurement.
Dielectric Resonator Antenna Oscillator (DRAO)
• The DRA is used as the oscillator load, named as DRAO.

• The reflection amplifier method is used to design the antenna oscillator.
DRAO Schematic Diagram

- Oscillate condition: \( X_L + X_{\text{in}} = 0 \) & \( R_L < |R_{\text{in}}| \)
- DRA first replaced by a 50\( \Omega \) load at 1.85GHz.
Antenna Configuration:

Resonance frequency 
\[ f_0 = 1.85\text{GHz at } TE_{111}^y \]

Parameters:
DRA 
- \( L = 52.2\text{mm}, \) 
- \( W = 42.4\text{mm}, \) 
- \( H = 26.1\text{mm}, \) 
- \( \varepsilon_r = 6. \)

Aperture 
- \( L_a = 0.3561\lambda_e, \) \( W_a = 2\text{mm} \) 
- \( L_s = 9.5 \text{ mm}, \) \( L_m = 40 \text{ mm}. \)

Duroid substrate 
- \( \varepsilon_{rs} = 2.94, \) \( d = 0.762\text{mm} \)
• Good agreement.
• Bandwidth ~ 22.14%.
• Resonance frequency: Measured 1.86GHz
  Simulated 1.83GHz (1.5% error).
Spectrum of the Free-running DRAO

- Transmitting power $P_t = 16.4$ dBm
- DC-RF efficiency: $\sim 13\%$ (2-25% in the literature).
- Phase noise: 103 dBc/Hz at 5 MHz offset
- Second harmonic $<$ fundamental by 22 dB
• Broadside TE$_{111}^y$ is observed.
• Co-polarized fields are generally 20dB stronger than the cross-polarized fields in the boresight direction.
DRA can be of any shape. Can it be made like a swan?

Yes!

DRA is simple made of dielectric. Can glass be used for the dielectric?

Yes!

It leads to probably the most beautiful antenna in the world …….
Glass-Swan DRA

Distinguished Lecture
Transparent antennas: From 2D to 3D
Conclusion

• The DRA can be easily excited with various excitation schemes.

• Frequency tuning of the DRA can be achieved by using a loading-disk or parasitic slot.

• The dualband and wideband DRAs can be easily designed using higher-order modes.

• Compact omnidirectional CP DRAs have been presented.

• Dualfunction DRAs for packaging and oscillator designs have been demonstrated.
Thank you!
Q & A