Wireless Sensor Networks and Internet of Things: Technologies and Applications

Antenna Miniaturization for WS Nodes

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Outline

✓ Microwave and Antennas Research Lab. at Ain Shams University
✓ Antennas for Wireless Sensors Networks
✓ Research conducted at the MW Lab
  • Multi-band antennas
  • Wide-band antennas
  • Millimeter wave antennas
✓ Conclusions
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MARL: Personnel

Lab. founder
Late Prof. Safwat Mahrous

Lab. members
Prof. Hadia Elhennawy, (Group leader)
Prof. Amr M. E. Safwat (Lab. Director)
Eng. Mostafa Gamal, TA/RA
Eng. Mohamed Ibrahim, TA/RA
Eng. Sally El-Henawy, TA/RA
Eng. Mahmoud Mabrouk, TA/RA
Eng. Abdelhameed Hatem, TA/RA
Eng. Islam Mashaly, RA

On leave
Prof. Hani Ghali       Dr. Marwa Abdelaziz
MARL: Location
MARL: Facilities

- Antenna measurement (anechoic) room 0.7 GHz-18 GHz
- Home-made antenna room (1-3 GHz)
- Anritsu Vector Network Analyzer (70 GHz).
- Rhode & Schwartz Vector Network Analyzer (14 GHz).
- PCB fabrication facilities (chemical etching).
- EM simulators (HFSS).
- Circuit simulators (ANSYS Designer and AWR Microwave Office).
0.7-18 GHz Anechoic Chamber
0.7-18 GHz Anechoic Chamber
0.7-18 GHz Anechoic Chamber
0.7-18 GHz Anechoic Chamber
Home-made Antennas Measurement Setup
Anritsu VNA (70 GHz)
Microwave and Antennas Research Lab. at Ain Shams University

Antennas for Wireless Sensors Networks.

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  • Multi-band antennas
  • Wide-band antennas
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Conclusions
Antennas for Sensor Applications

(a) Typical scheme of a wireless smart sensor system; (b) tentative implementation [2]

Antennas for Sensor Applications

Printed monopole on a dielectric substrate.

Printed dipole antenna integrated with electronics, sensors and battery onto paper.

Printed (embroidered) patch antenna onto textile for on-body sensor systems.

Patch antenna printed on a MMIC substrate.

Printed antennas developed in 3D arrangements

Body-Centric Wireless Communications

- Small and lightweight
- Limited radiation power in the direction of the wearer
- Textile conformal antennas to provide user-friendly solutions
- Surface guided wave antenna to improve on-body communications
- Immune from de-tuning and performance degradation due to surrounding components and when placed on the body.
- Have high efficiency
- Overcome shadowing problems caused by the human body and the dynamic environment.

http://antennas.eecs.qmul.ac.uk/research/body-centric-wireless-communication-and-networks/
Specifications of WSN Antennas

• Depending on the applications, antennas may be single band, multi-band or wide band.
• Also, they can be either directive or directional.
• However, for all applications, it is expected that antennas should be:
  ➢ Compact in size
  ➢ Efficient
  ➢ And low profile.
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Multi-Band Metamaterial-Inspired Antennas

\[ L_s \quad W_4 \quad W_5 \quad L_5 \quad W_3 \quad W_2 \quad W_1 \quad L_2 \quad L_1 \]

\[ 2L_{\text{shunt}} \quad C_{\text{shunt}}/2 \quad C_{\text{shunt}}/2 \quad 2L_{\text{shunt}} \]

\[ L_{\text{series}} \quad C_{\text{series}} \]

\[ \beta \phi (\text{rad}) \]

\[ \text{Frequency (GHz)} \]

\[ S_{11} (\text{dB}) \]

Conventional monopole - Solid line
Modified monopole - Dashed line

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Multi-Band Metamaterial-Inspired Antennas

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Radiation Pattern Measurements

Multi-band Planar Monopole

Conventional monopole

3-band monopole

5-band monopole

One Unit Cell

$\textit{f}_{\text{transition}} = f_n$

Two Unit Cells

$\textit{f}_{\text{transition}} = f_{n-1}$

Four Unit Cells

$\textit{f}_{\text{transition}} = f_{n-2}$

| Frequency (GHz) | $|S_{11}|$ (dB) |
|-----------------|---------------|
| 0.70            |               |
| 1.00            |               |
| 1.30            |               |
| 1.60            |               |
| 1.90            |               |
| 2.20            |               |
| 2.50            |               |
| 2.80            |               |

Simulations

Measurements

CLRH Loaded Printed-IFA


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Dual-Band Orthogonal-Beam CRLH Loop antenna
Dual-Band Orthogonal-Beam CRLH Loop antenna

M. Ibrahim, S. Elhenawy and A. Safwat, EuMC, (2013)
Slow-Wave Printed IFA

N-Internal Port Design for Wide Band ESAs

\[
\begin{bmatrix}
Z_{1,1} - Z_{\text{Bank}} & Z_{1,2} & \cdots & Z_{1,n+1} \\
Z_{2,1} & Z_{2,2} + Z_{\text{Lumped1}} & \cdots & Z_{2,n+1} \\
\vdots & \vdots & \ddots & \vdots \\
Z_{n+1,1} & Z_{n+1,2} & \cdots & Z_{n+1,n+1} + Z_{\text{Lumped}_n}
\end{bmatrix}
\begin{bmatrix}
i_1 \\
i_2 \\
\vdots \\
i_{n+1}
\end{bmatrix} = 0
\]
N-Internal Port Design for Wide Band ESAs

\[
\begin{bmatrix}
Z_{1,1} - Z_{Bank} & Z_{1,2} \\
Z_{2,1} & Z_{2,2} + Z_{lumped}
\end{bmatrix}
\begin{bmatrix}
i_1 \\
i_2
\end{bmatrix} = 0
\]

\[
Z_{lumped} = \frac{Z_{1,2}Z_{2,1}}{Z_{1,1} - Z_{Bank}} - Z_{2,2}
\]

![Diagram](image_url)

- Disk solution
- Annulus solution

- Frequency (GHz)
  - Unloaded dipole
  - Dipole with one 17.7 nH inductor
  - Dipole with open circuit

- |S11| (dB)
  - 1.05 GHz
  - 1.92 GHz
  - 3.36 GHz
  - 4.43 GHz

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DVB Handheld Antenna

USB Size Wide Band Z-based Antennas
1.7- 4.7 GHz Antenna

60 GHz Antenna

Objective.

- Realize an efficient compact-size antenna that operates at 60 GHz using 65 nm technology.

Funding agency: National Telecommunication Regulatory Authority (NTRA)
Artificial Magnetic Conductor (AMC)

- The simplest AMC implementation is $\lambda/4$ short-circuited transmission line.
- A capacitive layer is added to control the operating frequency.

![Diagram of AMC structure](image_url)

- Silicon ($\varepsilon_r=11.9$)
- $T_{sub}=280 \mu m$
- $\sigma \approx 10 \text{ S/m}$

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65 nm AMC

- The resonance frequency of the grounded substrate is 79 GHz.
- To shift the resonance frequency to 60 GHz a capacitance of 9 pF has to be added.
- Extra losses occur due to the fringing of the electric fields.
To maximize $R_f$, there are two solutions.

- The unit cells are implemented on higher metal layers to decrease the fringing losses.
- Unit cells are implemented on two metal layers.

![Graph showing |S11| vs Frequency for different AMC implementations.](image-url)
AMC-loaded Dipole Antenna

Frequency (GHz)

Imaginary Part of Z

$\ImaginaryPart_{Z_1}$ (Ω)

$f_1 = 42$ GHz  $f_2 = 72$ GHz

Dipole (HFSS)  Dipole (CST)  AMC (HFSS)  AMC (CST)  Dipole with AMC

Radiation Efficiency

Total Efficiency


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AMC-Loaded Dipole Antenna

\[ |S_{11}| \text{ (dB)} \]

\[ \text{Frequency (GHz)} \]

\[ \text{Radiation Efficiency} \]

\[ \text{Total Efficiency} \]

\[ \text{x-z plane, } f = 60 \text{ GHz} \]

\[ \text{y-z plane, } f = 60 \text{ GHz} \]
### Performance Summary

<table>
<thead>
<tr>
<th>Reference</th>
<th>Bandwidth / Frequency</th>
<th>Gain / Efficiency</th>
<th>Area</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chu, et. al., RFIT, 2009</td>
<td>56 GHz to 66 GHz</td>
<td>-2.5 dBi &amp; 15%</td>
<td>1.55 mm × 1.55 mm</td>
<td>Patch &amp; AMC &amp; LP</td>
</tr>
<tr>
<td>Bao, et. al., TAP, 2012</td>
<td>57 GHz to 67 GHz **</td>
<td>-5 dBi</td>
<td>1.8 mm × 1.8 mm</td>
<td>Loop &amp; AMC</td>
</tr>
<tr>
<td>Pan, et. al., APS, 2011</td>
<td>85 GHz to 97 GHz</td>
<td>1.2 dBi</td>
<td>2 mm × 1.2 mm</td>
<td>Dipole &amp; AMC</td>
</tr>
<tr>
<td>This Work</td>
<td>42 GHz to 68 GHz</td>
<td>2 dBi &amp; 52%</td>
<td>1.8 mm × 1.2 mm</td>
<td>Dipole &amp; Two-layer AMC</td>
</tr>
</tbody>
</table>

- The front to back ratio is 8.8 dB.
- The beamwidth is 150°

** The Axial Ratio BW is from 57 GHz to 67 GHz

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From antenna perspective the loop sounds to be complete.

✓ Software tools are available for the design phase.
✓ Implementation can be conducted within the available technologies in Egypt (printed circuit board)
✓ Characterization for connectorized antennas is also available (Network analyzer and anechoic chamber).
Thank You