OLED Display-Integrated Optically Invisible Phased Arrays for Millimeter-Wave 5G Cellular Devices

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Outline

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- Verification: Experimental Verification
- Demonstration: mmWave 5G Smartphone Prototype
- Summary & Conclusion
1. Background: Trends in Mobile Terminal

Study and Prototyping of Practically Large-Scale mmWave Antenna Systems for 5G Cellular Devices

Wonbin Hong, Kwang-Hyun Baek, Youngju Lee, Yoongeon Kim, and Seung-Tae Ko
1. Background: Trends in Mobile Terminal


1. **Background**: Trends in Mobile Terminal

- 1st Generation mmWave 5G smartphone are now commercially available in North America as of 3Q of 2019.
- mmWave modules are mounted on the back side of the devices
- mmWave 5G AiPs must be implemented at pre-designated location within devices.

→ Restricts [frontside] beam coverage and design/ergonomic flexibilities

**LG V50**  
**Samsung Galaxy S10**  
**World's First 5G Upgradable Smartphone**

(Source: LG)  
(Source: Samsung)  
(Source: Motorola)
2. Proposal: Invisible Antennas and RF circuits

Antenna-on-Display (AoD) Concept for portable mmWave beamforming

- Display panels increasingly occupy majority of the wireless device aperture.
- Monolithic integration of optically invisible antenna arrays in the active display region is proposed for future mmWave 5G mobile devices.
2. Proposal: Invisible Antennas and RF circuits

◊ Antenna-on-Display (AoD) and Transparent antennas are conceptually different.

2. Design: Electrical Characteristics of Thin Film Alloy

- In order to ensure optical transparency, the thickness of Ag-alloys must be confined to several hundreds of nanometers.
- The insertion loss characteristics is further examined using a series of fabricated Ag-alloy CPW test samples.

\[ S_{21} \text{ (dB)} \]

\[
\begin{align*}
\text{Frequency (GHz)} & : 0 & 10 & 20 & 30 \\
S_{21} & : -4 & -3 & -2 & -1 \\
\text{Measured (Solid line)} & & & & \\
\text{Simulated (Dotted line)} & & & & \\
\end{align*}
\]

\[ S_{21} \text{ (dB)} \]

\[
\begin{align*}
\text{Frequency (GHz)} & : 0 & 10 & 20 & 30 \\
S_{21} & : -4 & -3 & -2 & -1 \\
\text{Mea. } S_{21} \text{ of } w_{\text{mesh}} = 5 \mu m & & & & \\
\text{Sim. } S_{21} \text{ of } w_{\text{mesh}} = 5 \mu m & & & & \\
\text{Mea. } S_{21} \text{ of } w_{\text{mesh}} = 3 \mu m & & & & \\
\text{Sim. } S_{21} \text{ of } w_{\text{mesh}} = 3 \mu m & & & & \\
\end{align*}
\]

\(< S_{21} \text{ of the 2 mm-long CPW as a function of the thickness of Ag-alloy. Black Square: } t = 2000 \text{ Å; Red Triangular: } t = 1000 \text{ Å; Blue Circle: } t = 700 \text{ Å} >

\(< S_{21} \text{ of the transparent 10 mm-long CPW as a function of } w_{\text{mesh}} >\)
The proposed AoD concept will be instrumental in resolving the prolonging trade-off relations between antenna system performance and aesthetical value.
2. Design: Transparent AoD element

- A transparent diamond grid antenna element consisting of diamond-grid unit cells is designed and fabricated.
- The radiation patterns demonstrate a great agreement between measurement and simulation.

*Photograph of the fabricated transparent diamond grid antenna >

*S\textsubscript{11} of the proposed antenna >

- Sim : 26.65 – 27.28 GHz
- Mea : 27.9 – 29.1 GHz

*Normalized radiation patterns >

- Simulated Dir : 6.86 dBi
- Measured gain : 4.05 dBi
2. **Design: Optically Invisible AoD element**

- Despite the high optical transparency, the outer trace lines of the aforementioned transparent antenna are detectable to the human eye when placed above light emitting displays.

< Optically transparent AoD >

< Optically invisible AoD >
2. Proposal: Invisible Antennas and RF circuits

Step. 1.
Antenna element
- Optimization
- Optical Invisibility

Step. 2.
Phased antenna array
- Array Configuration
- Integration of 5G IC

- The proposed AoD concept will be instrumental in resolving the prolonging trade-off relations between antenna system performance and aesthetical value.
2. Design: Optically Invisible AoD Phased Array

- The transparent diamond grid antenna elements are extended to an 8-element array configuration for potential beamsteering applications.

< The proposed invisible multilayer antenna array considering display integrated application >

< GSG input Port (L3) >
2. Design: Optically Invisible AoD Phased Array

- The feeding network (L3) and eight antenna elements (L4) are separately devised and integrated using an anisotropic conductive film (ACF) bonding process.
3. Experimental Verification : Measurement Result

- The antenna pattern is indistinguishable in the optically invisible diamond grid antenna array structure as compared to the transparent diamond grid antenna array.

- The measured results of transparent and invisible antenna arrays feature 4.42 GHz (25.48 – 29.9 GHz) and 5.55 GHz (24.23 – 29.78 GHz) respectively.

< Photograph of the fabricated transparent and optically invisible diamond grid antenna array >

< Measured and simulated reflection coefficient $|S_{11}|$ of the fabricated antenna arrays >
3. Experimental Verification: Measurement Result

- The 8-element array configuration consisting of transparent antenna element is designed and fabricated.
- The radiation patterns demonstrate a great agreement between measurement and simulation.

(a) E-plane
- Simulated Dir: 12.83 dBi
- Measured gain: 6.66 dBi

(b) H-plane

< Photograph of the fabricated optically invisible diamond gird antenna array >

< Normalized radiation patterns of the fabricated antennas >
3. Experimental Verification: Measurement Result

- Phased-array properties are emulated using 8:1 power-dividing feeding networks consisting of tapered impedance transformers and T-junctions.

- The array structure achieves a scanning angle of approximately 40° using the feeding networks with fixed sequential phase delays.

< 1:8 feeding network (a) in-phase, (b) 120 ° phase difference >  < Normalized radiation patterns of the fabricated antennas >
4. Integration: 5G Hybrid Antenna Module

- The hybrid antenna module concept coherently combines two existing concepts - AiP (Antenna-in-Package) and AoD (Antenna-on-Display).
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4. Integration: 5G Hybrid Antenna Module

- The hybrid antenna module concept coherently combines two existing concepts - **AiP** (Antenna-in-Package) and **AoD** (Antenna-on-Display).

- RF chains are selectively activated using opportunistic beamforming algorithm.
4. Demonstration: mmWave 5G Smartphone Prototypes

- Proof-of-Concept (POC) Model by POSTECH 5G Consortium

Photograph of the fabricated mmWave 5G Smartphone prototypes

Measured normalized beamforming radiation patterns

(accepted for publication)
4. Demonstration: mmWave 5G Smartphone Prototypes

- Proof-of-Concept (POC) Model: Verified with 28 GHz 5G FR2 Network Evaluation (Courtesy of SK Telecom)
- Verified to meet 5G FR2 Signal quality requirements

<table>
<thead>
<tr>
<th>Measured Constellations at Different Modulations</th>
<th>Carrier frequency: 28 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK 1CC 400 MHz</td>
<td>16-QAM 1CC 400 MHz</td>
</tr>
<tr>
<td>EVM 4.9 %</td>
<td>EVM 5.1 %</td>
</tr>
<tr>
<td>64-QAM 1CC 400 MHz</td>
<td>64-QAM 2CC 800 MHz</td>
</tr>
<tr>
<td>EVM 5.2 %</td>
<td>EVM 7.2 %</td>
</tr>
</tbody>
</table>

Photograph of the fabricated mmWave 5G Smartphone prototypes

(accepted for publication)
5. Conclusion

- **Investigated** the **basic requirement** and **challenges** for designing mmWave 5G antenna systems.

- **Proposed** the concept of Antenna-on-Display (AoD) for future mmWave 5G wireless applications.
  :
  - Measured gain of 9.16 dBi (efficiency of 41.2 %), beam scanning angle $> \pm 60^\circ$

- **Achieved optical invisibility** with the inclusion of identical dummy grids that surround the antenna and transmission line.
  :
  - Optical transparency of 88 %, Haze of 2.8 %

- **Demonstrate mmWave 5G smartphone prototype** and **beamforming strategies** for future 5G mobile terminals.

  - The proposed antenna system opens up another axis for implementing mmWave 5G mobile antenna systems.
Thank you for your attention
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Reference


