Switchable Antenna Polarization using Surface-Integrated Fluidic Loading Mechanisms


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This work was sponsored in part by AFOSR grant # FA9550-08-1-0329 and the NASA funded Space Engineering Institute at Texas A&M University

Space Engineering Institute
Affiliated with Texas A&M University, Dwight Look College of Engineering

NASA

Small Satellite 2010 Logan, Utah
August 12, 2010 Mission Enabling Technologies 2
Project Team and Acknowledgements

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Outline

- Motivation and Current Technology
- Polarization Reconfigurable Antenna
- Analytical Model
- Mechanism 1: Fluid Displacement
- Mechanism 2: Electrokinetic Effects
- Summary and Future Research

[www.radantmems.com]

[Courtesy NASA/JPL-Caltech]
Polarization Reconfigurable Antenna

Fluidic and Electrokinetic Reconfiguration Mechanisms

- **Mechanism 1: Fluid Displacement**
  - Alternate periodic high/low permittivity dispersions across gaps
  - Retune antenna to alter polarization at fixed frequency by circulating sections of fluid ¼ turn

- **Mechanism 2: Electric Field Assisted Microstructure**
  - Use applied bias to alter particle alignment (random/aligned permittivity)
  - Each arm can be independently controlled/biased
  - Reconfigure polarization
Mechanism 1: Fluid Displacement

Antenna with Connectorized Fluidic Displacement System

Dimensions in mm

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<tr>
<th>H₁</th>
<th>H₂</th>
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Mechanism 1: Fluid Displacement

Antenna with Connectorized Fluidic Displacement System

Peristaltic pump  Syringe pump  COMSOL simulation of fluid flow 1 psi

Representation of Assembly

Adapter  Channel  Inflow/Outflow

Fabricated from PDMS
($\varepsilon_r \sim 2.66$ and $\tan \delta_e \sim 0.03$) and
ABS plastic
($\varepsilon_r \sim 2.72$ and $\tan \delta_e \sim 0.007$)
using a rapid prototype machine
Mechanism 1: Fluid Displacement

1. Mix PDMS
2. Release Agent
3. PDMS Negative
4. PDMS Capillary

Results:
- Fabricated Antenna
- PDMS Adhesive
- Milling Machine
Analytical Model

Use of a Dispersion with Periodic High-Low Dielectric on Gaps

High/Low Permittivity

$\varepsilon_r = 77.15 / \varepsilon_r = 2.1$

Note: Water emulates high dielectric fluid
Mechanism 1: Fluid Displacement

**Utilizing Dynamic Material/Fluidic-Based Material Systems**

Mixing rules play a large role in the development and use of these systems and need to be used judiciously…

**Barium Strontium Titanate (BSTO)**

\[ \text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3 \]

(\(\varepsilon_r \approx 1000, \mu_r \approx 1, \text{and} \tan \delta_e \approx 0.05\))

Particle Diameter <100nm

**Petroleum Distillate Oil**

(\(\varepsilon_r \approx 2.1, \mu_r \approx 1, \text{and} \tan \delta_e \approx 0.001\))
Mechanism 1: Fluid Displacement Summary

Use of a Dispersion with Periodic High-Low Dielectric on Gaps

High/Low Permittivity
\[ \varepsilon_r = 77.15 / \varepsilon_r = 2.1 \]

- Analytical
- Simulated
- Measured

Freq. = 2.438 GHz
Freq. = 2.443 GHz
Mechanism 1: Fluid Displacement Summary

Use of a Dispersion with Periodic High-Low Dielectric on Gaps

High/Low Permittivity

$\varepsilon_r = 77.15 / \varepsilon_r = 2.1$

- Blue: Analytical
- Red: Simulated
- Black: Measured

Freq. = 2.438 GHz
Freq. = 2.443 GHz
Mechanism 1: Fluid Displacement Summary

Use of a Dispersion with Periodic High-Low Dielectric on Gaps

**High/Low Permittivity**

\[ \varepsilon_r = 77.15 / \varepsilon_r = 2.1 \]

- **Analytical**
- **Simulated**
- **Measured**

Freq. = 2.438 GHz
Freq. = 2.443 GHz
Mechanism 2: Electrokinetic Effects

Morphology of Microfluidic Systems

Electric field mediated reversible assembly of 800nm colloidal gold particles

Tunable resistance/capacitance in micro-electronic/fluidic device

Mechanism 2: Electrokinetic Effects

**Fluidic Displacement and Biased Electrokinetic Systems**

**Dimensions in mm**

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Mechanism 2: Electrokinetic Effects

Utilizing Dynamic Material/Fluidic-Based Material Systems

Petroleum Distillate Oil
\((\varepsilon_r \sim 2.1, \mu_r \sim 1, \text{ and } \tan \delta_e \sim 0.001)\)

Nanowhisker BTO
Radius \(\sim 5\) nm, Length \(\sim 40\) nm
\((\varepsilon_r \sim 1000, \mu_r \sim 1, \text{ and } \tan \delta_e \sim 0.05)\)

Maxwell Garnett Mixing Rule for Random Orientation
\[
\varepsilon_{\text{eff}}(\vartheta) = \varepsilon_r + \vartheta(\varepsilon_r - \varepsilon_1) \frac{\varepsilon_r + 5\varepsilon_1}{(3 - 2\vartheta)\varepsilon_r + (3 + 2\vartheta)\varepsilon_1}
\]

Maxwell Garnett Mixing Rule for Aligned Orientation
\[
\varepsilon_{\text{eff}}(j) = \varepsilon_1 + \vartheta_j \frac{\varepsilon_j - \varepsilon_r}{\varepsilon_1 + (1 - \vartheta_j)N_j(\varepsilon_j - \varepsilon_r)}
\]
\[
N_y = N_z = 0.5, N_x = 0
\]
Particle Polarization

Utilizing Dynamic Material/Fluidic-Based Material Systems

Petroleum Distillate Oil
$(\varepsilon_r \sim 2.1, \mu_r \sim 1, \text{ and } \tan \delta_e \sim 0.001)$

Nanowhisker BTO
Radius $\sim 5$ nm
$(\varepsilon_r \sim 1000, \mu_r \sim 1, \text{ and } \tan \delta_e \sim 0.05)$

Nanowhisker BTO Length [nm]
$40$
$200$
$279,000$
Particle Polarization

Utilizing Dynamic Material/Fluidic-Based Material Systems

**Petroleum Distillate Oil**
(\(\varepsilon_r \sim 2.1, \mu_r \sim 1, \text{ and } \tan \delta_e \sim 0.001\))

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Mechanism 2: Electrokinetic Effects

Use of a Dispersion with Electrokinetic Effects on Gaps

Note: Water emulates dielectrophoresis chaining
Mechanism 2: Electrokinetic Effects

*Use of a Dispersion with Electrokinetic Effects on Gaps*

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Freq. = 2.438 GHz
Mechanism 2: Electrokinetic Effects

Use of a Dispersion with Electrokinetic Effects on Gaps

Note: Water emulates dielectrophoresis chaining

Freq. = 2.438 GHz
Software Defined Radio

Software controls the USRP and the Microcontroller

**USRP**
- Sends/Receives the Signal
- Performs Analysis on Signal
  - Determines the Bit Error Rate

**Microcontroller**
- Turns the pump on and off
  - Supplies or doesn’t supply voltage
- Duration depends on pump and capillaries (~1s)
Summary and Future Research

Polarization Reconfigurable Antenna

- 1st mechanism achieved by switching nano-dispersion volume fraction
  - Surface mounted microfluidic network design
  - Analytical representation
  - Measured results
- 2nd mechanism achieved by dielectrophoresis
  - Bias line implementation
  - New BTO nanowhiskers
  - Control integration with software defined radio

Future Research

- Microgravity testing
- Continue nanowhisker development
- Electrokinetic characterization of materials
- PRA testing with nanowhiskers and software defined radio
- Examining array reconfiguration
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