Polarization Independent and Highly Efficient Electromagnetic Energy Harvesting Using Metasurfaces

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Abstract

Recently electromagnetic (EM) energy harvesting using metasurfaces has gained a great attention. This presentation shows a single band and a double band polarization-independent metasurface harvesters composed of an ensemble of new resonators with a full level of symmetry in a way that their behavior is very insensitive to the polarization of the incident wave. Loading the resonators with resistors (which model the input impedance of a rectifying circuit in a harvesting system), it is shown that the metasurface perfectly absorbs the incident EM wave (regardless of its polarization) and perfectly delivers the absorbed power to the loads.

Index terms: Metasurface, energy harvesting, pixelization
Biography

Bagher Ghaderi was born in Shahrood, Iran. He received the B.Sc degree from the University of Tabriz, Shahrood, Iran in 2011 and the M.Sc degree from the Iran University of Technology (IUST), Tehran, Iran in 2017 both in electrical engineering. Her research interests include energy harvesting, antennas and radar systems.

Vahid Nayyeri was born in Tehran, Iran. He received the B.Sc. degree from the Iran University of Science and Technology (IUST), Tehran, Iran, in 2006, the M.Sc. degree from the University of Teheran, Tehran, Iran, in 2008, and the Ph.D. degree from the IUST in 2013, all in electrical engineering. From 2007 to 2010, he worked as an RF-circuit designer at the IUST satellite research center. He then was the technical manager of three research and industrial projects at the Antenna and Microwave Research Laboratory at IUST. In June 2012 he joined the University of Waterloo, Waterloo, ON, Canada, as a visiting scholar. Presently, he is an assistant professor of the department of satellite engineering, IUST, and also serves as vice-director of Antenna and Microwave Research Laboratory. He has authored and co-authored one book (in Persian) and over 50 journal and conference technical papers. He has been collaborating with Professor Omar M. Ramahi's group at University of Waterloo, since 2012. His research interests include applied and computational electromagnetics and microwave circuit design. In 2014, Dr. Nayyeri received the “Best Ph.D. Thesis Award” from the IEEE Iran Section for his research on the modeling of complex media and boundaries in the finite-difference time-domain method. He is a senior member of IEEE and has served as reviewer to several journals and conferences.

Mohammad Soleimani received the B.Sc. degree in electrical engineering from the University of Shiraz, Shiraz, Iran, in 1978 and the M.Sc. and Ph.D. degrees from Pierre and Marie Curio University, Paris, France, in 1981 and 1983, respectively. He is currently a professor with the school of electrical engineering, Iran University of Sciences and Technology, Tehran, and serves as director of the Antenna and Microwave Research Laboratory. He has also served in many executive and research positions. He has authored and coauthored 19 books (in Persian) and over 200 journal and conference papers. His research interests include electromagnetics, high frequency electronics, antennas.

Omar M. Ramahi was born in Jerusalem, Palestine. He received the BS degree in Mathematics and Electrical and Computer Engineering (Highest Honors) from Oregon State University, Corvallis, OR. In 1990, he was awarded the Ph.D. degree in Electrical and Computer Engineering from the University of Illinois at Urbana- Champaign (UIUC). He then worked at Digital Equipment Corporation (presently, HP), where he was a member of the Alpha Server Product Development Group. In 2000, he joined the faculty of the James Clark School of Engineering at the University of Maryland at College Park as an Assistant Professor and later as a tenured Associate Professor. At Maryland he was also a faculty member of the CALCE Electronic Products and Systems Center. Presently, he is a Professor in the Electrical and Computer Engineering Department, University of Waterloo, Canada. He has authored and co-authored over 400 journal and conference technical papers on topics related to the electromagnetic phenomena and computational techniques to understand the same. He is a co-author of the book EMI/EMC Computational Modeling Handbook, (first edition: Kluwer, 1998, Second Ed: Springer-Verlag, 2001. Japanese edition published in 2005). Professor Ramahi is the winner of the 2004 University of Maryland Pi Tau Sigma Purple Cam Shaft Award. He won the Excellent Paper Award in the 2004 International Symposium on Electromagnetic Compatibility, Sendai, Japan, and the 2010 University of Waterloo Award for Excellence in Graduate Supervision. In 2012, Professor Ramahi was awarded the IEEE Electromagnetic Compatibility Society Technical Achievement Award.
EM Energy Harvesting

Harvesting from Ambient RF Energy
EM Energy Harvesting

Long Range Wireless Power Transfer
Harvesting System

Greater amount of energy, larger antenna area:

- Large aperture antennas: heavy and expensive
- Antenna arrays
Recently, planar array of small resonators (metasurface) has been shown to provide a better efficiency than regular antenna arrays like microstrip patch antennas.

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\[ \eta = \frac{\text{effective area}}{\text{physical area}} = \frac{P_{\text{rec}}}{P_{\text{inc}}} \]

It has been experimentally shown that it is possible to collect the harvested energy from each cell.

The behavior of a metasurface harvesters is similar to that of a metamaterial absorbers; however, there is a distinct difference between them:

- In both structures, the resonators efficiently couple to the EM wave in the free space.

- For a harvesting application, the captured microwave energy must be channeled to a resistive load (a grounded resistor) which models the input impedance of a feed network or rectifying circuit in a complete harvesting system.

- In metamaterial absorbers, the absorbed wave dissipates either in the structure as dielectric and copper losses or lumped resistors which are placed between two sections of a resonator.
In the Literature (Wideband)

In the Literature (near unity efficiency)

Proposed Resonator for Dual Pol.

### Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( l )</th>
<th>( w_1 )</th>
<th>( w_2 )</th>
<th>( s )</th>
<th>( g )</th>
<th>via diameter</th>
<th>( R )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>10.5 mm</td>
<td>0.5 mm</td>
<td>1.2 mm</td>
<td>0.4 mm</td>
<td>0.8 mm</td>
<td>0.7 mm</td>
<td>160 ohms</td>
</tr>
</tbody>
</table>

**Dielectric substrate:** Rogers RT/duroid 6006, thickness 100 mil
Surface Current Density

\[ \phi = 90^\circ \]

\[ \phi = 60^\circ \]

\[ \phi = 45^\circ \]
Unit Cell Performance

\[ \eta = \frac{P_{\text{loads}}}{P_{\text{inc}}} \]

\[ P_{\text{inc}} = (\text{Power Density}) \times (\text{Unit Cell Area}) \]

Absorption Performance

Harvesting Performance
Fabricated Array

Top View

Bottom View
Measurement Setup

- Transmitter horn
- Antenna
- R = 7.5 m
- Signal generator
- Spectrum analyzer
- Metasurface harvester
- 50 to 200 Ω converter
- 50 Ω cable
- SMA connector
- 50 Ω cable
Measurement Setup
The simulated and measured output power of the central cell for different polarization angles of the incident field.
Results

The measured power for different polarization angles
Resonator for Dual Pol. & Dual Band

Top View

Bottom View

via

load

Ground plane
Resonator for Dual Pol. & Dual Band

Not good efficiency in both bands 😞

![Graph showing efficiency vs frequency with multiple curves labeled phi=0, phi=30, phi=45, phi=30, phi=90.](image-url)
Pixelated Checkerboard Metasurface for Ultra-Wideband Radar Cross Section Reduction

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Received: 20 June 2017
Accepted: 29 August 2017
Published online: 12 September 2017
Pixelated Cell
Results

Great efficiency in both bands 😊

![Graph showing efficiency vs frequency with markers for different \( \phi \) angles: \( \phi = 0 \), \( \phi = 30 \), \( \phi = 45 \), \( \phi = 60 \), \( \phi = 90 \).]
Fabricated Array
Thanks for Your Attention!
Any Question?
References


