Employing Phase-Conjugation Antenna Array to Beam Microwave Power from Satellite to Earth

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December 2015
Large Antenna Array for SSP

- From outer space to earth
  - GigaWatt-level solar power
  - Narrow microwave beam

- Large antenna array

- Earth not in far-field zone

- Adjust beam in real time

- Phase-conjugation array
  - Retro-directive array?
  - Retro-reflective array?

$y = 36,000 \text{ km}$
Introduction

Analysis of phase-conjugation array (for SSP)

Some experimental results (not for SSP)

Summary
Conventional Phased Array

All elements fed in phase
5.8 GHz
Spacing: half wavelength (25 cm)

Microwave beam

y = 36,000 km

Earth

y

40 dBi
Conventional Phased Array

All elements fed in phase
5.8 GHz
Spacing: half wavelength (25 cm)

Array aperture | 3-dB beamwidth | Over earth surface
--- | --- | ---
1 m | 2.6 | Diameter 1,634 km
Conventional Phased Array

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Phase-Conjugation Array

Earth

Pilot signal

Microwave beam

x

y

z
Retro-Directive Array

Incident plane wave

Plane wave in far-field
Received Phase Distribution

Earth

Pilot signal

1 km

z

x

y

z (m) 0

-500

x (m) 500

-500

0

500

-50

-100

-200

-300

-400

-500

(degree)

0

-10

-20

-30

-40

-50
Retro-Reflective Array

Pilot signal

Power beam
Retro-Reflective Array

Focusing coefficient 0.94 0.96 0.98 1

x

y (1,000 km)

z

47

36,000 km

0 50 100 150 200 250 300

y
Retro-Reflective Array

Focusing coefficient

- $0.94$
- $0.96$
- $0.98$
- $1$

Distance:
- $0$
- $50$
- $100$
- $150$
- $200$
- $250$
- $300$
- $350$
- $400$

$y$ (1,000 km)

$z$

$x$

$y$

36,000 km
Retro-Reflective Array

Focusing coefficient

\[
\begin{array}{c}
0.94 \\
0.96 \\
0.98 \\
1
\end{array}
\]

y (1,000 km)

x

z

0

47

y (1,000 km)

36,000 km
Retro-Reflective Scheme

- Base station
- Cable
- Charging panel
- Focused power beam
- Pilot signals
Retro-Reflection

- Regular reflection
- Incidence
- Reflection

- Retro-reflection + amplification
- Power guided by pilot signal

Pilot signals
Target

- Pilot signals
Retro-Reflective Scheme

Base station

Cable

Charging panel

Focused power beam

Pilot signals
Retro-Directive Setup

- Pilot signal processor
- Pilot signal
- Pilot signal generator
- Power transmitter
- Power receiver
Retro-Directive Setup

- RF power generator
- Power transmitter
- Power receiver
- Focused RF power beam
- Power meter or rectifier
**Retro-Directive Results**

**Peak power:** 7 mW

![Graph showing voltage over a 1.8-kΩ resistor with peaks at different x positions: x₀ = 0, x₀ = -10 cm, x₀ = -20 cm, and x₀ = -30 cm.]

**Transmitted power:** 4 x 250 mW

- Power transmitter
- Power receiver

\[ G_t = 9.8 \text{ dBi} \]
\[ G_r = 3.8 \text{ dBi} \]
\[ d = 50 \text{ cm} \]

Demo_140515_02.mpg
Retro-Reflective Setup

Receiver (monopole)
Retro-Reflective Results

- Pilot signal from (60 cm, 60 cm)
Retro-Reflective Results

- Pilot signal from (60 cm, 60 cm)

- Transmitted power

175 mW \( \equiv 8 = 1.4 \) W
Retro-Reflective Results

- Pilot signal from (70 cm, 70 cm)

Normalized $|E|^2$

$y = 70$ cm

$x = 70$ cm
Retro-Reflective Results

- **Pilot signal from**
  (70 cm, 70 cm)

- **Transmitted power**

  $175 \text{ mW} \times 8 = 1.4 \text{ W}$
Summary

- Large antenna array for SSP
- Earth not in far-field zone

- Phase-conjugation array
  - No longer retro-directive array
  - Retro-reflective array
  - Near-zone focusing

- Analysis results for SSP
- Experimental results in lab
  - Retro-directive
  - Retro-reflective
  - For SSP, hopefully in near future