Electromagnetic Analysis of Intelligent Reflecting Surface

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Abstract

Intelligent reflecting surfaces (IRSs) are a new type of reconfigurable metasurface that can be used to control the propagation of electromagnetic waves. This paper presents a MATLAB and Simulink code that can be used to perform the electromagnetic analysis of IRSs. The code is based on the finite element method and can be used to simulate the propagation of electromagnetic waves through a variety of IRS configurations. The code is also capable of generating the reflection coefficients for different incident configurations. The code is validated by comparing the results of the simulations with the results of analytical calculations. The results show that the code is able to accurately predict the performance of IRSs.

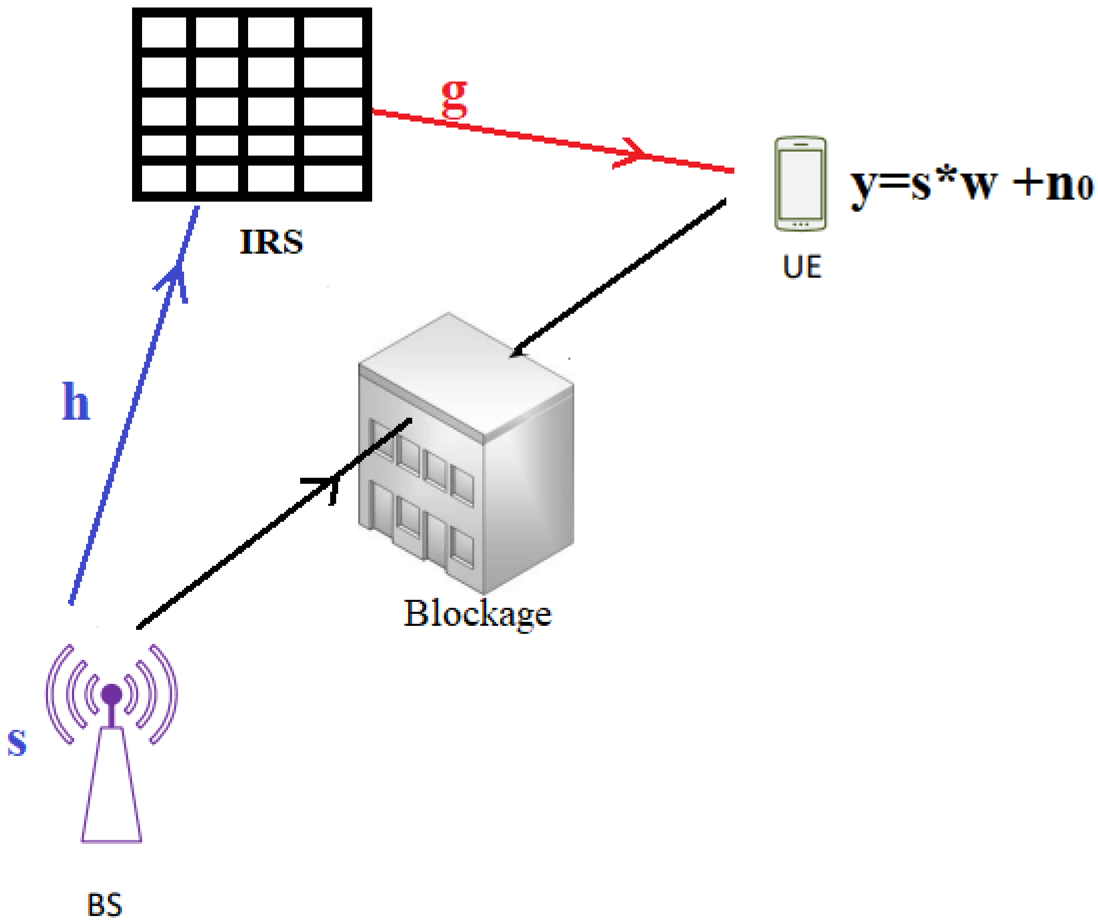
Electromagnetic Analysis of Intelligent Reflecting Surface

A reconfigurable intelligent surface (RIS) is a type of metasurface that can be used to control the propagation of electromagnetic waves. RISs are made up of a large number of small, individual elements that can be individually controlled. This allows the RIS to be used to shape the wavefront of the transmitted or received signal. This can be used to improve the signal strength, reduce interference, or increase the coverage area.

RISs are a promising new technology for improving the performance of wireless communication systems. They are still under development, but they have the potential to revolutionize the way we communicate.

Explanation

This example shows how to model the response of an intelligent reflecting surface (IRS) using full-wave electromagnetic simulation. The IRS, also known as the reconfigurable intelligent surface (RIS), large intelligent surface (LIS), or metasurface, has garnered significant interest in the wireless communication community. The IRS consists of a large array of subwavelength unit cell elements which can manipulate the phase, amplitude, polarization, or frequency of the incident signal. If an obstacle blocks the direct path between the base station (BS) and the user equipment (UE), the parasitic reflection of the IRS can provide an alternative path for signal transmission, as this figure shows. An external phase control mechanism can be integrated to control the reflection characteristics of the IRS.



The inclusion of the RIS provides a two-segment indirect path to the signal traveling between the BS and the UE. The first segment covers the path between the BS and the IRS. The second segment covers the path between the IRS and the UE. The channel matrix of these two signal paths depends on the geometry and the electromagnetic reflection properties of the IRS.

The signal received at the UE is represented mathematically in [1] using this equation.

$$r = sw + n_0 = s\frac{\sqrt{G_r G_u G_t A_r A_u}}{4\pi}\sum_{n=1}^{N}\frac{\sqrt{\widetilde{F}_n R}}{d_{tn}d_{rn}}e^{\frac{-j2\pi(d_{tn}+d_{rn})}{\lambda}} + n_0,$$

where

- $R = [R_1\, R_2 \ldots\ldots R_n]^T$.
- G_u is the embedded gain of the n^{th} IRS element.
- G_t is the embedded gain of the BS transmitter.
- G_r is the embedded gain of the UE receiver.
- $F_n = F_n^t F_n^r F_n^{tx} F_n^{rx}$ is the product of the normalized power patterns of the BS, UE, and IRS.
- d_t is the distance between the BS and the n^{th} IRS element.
- d_r is the distance between the UE and the n^{th} IRS element.
- A_r is the effective aperture area of the UE.
- A_u is the effective aperture area of the n^{th} IRS element.
- λ is the free-space wavelength.

For this example, assume that the IRS has N unit cell elements. The complex reflection coefficient of the n^{th} IRS element is denoted by $R_n = R_n^{mag} e^{j\tau_n}$.

Code

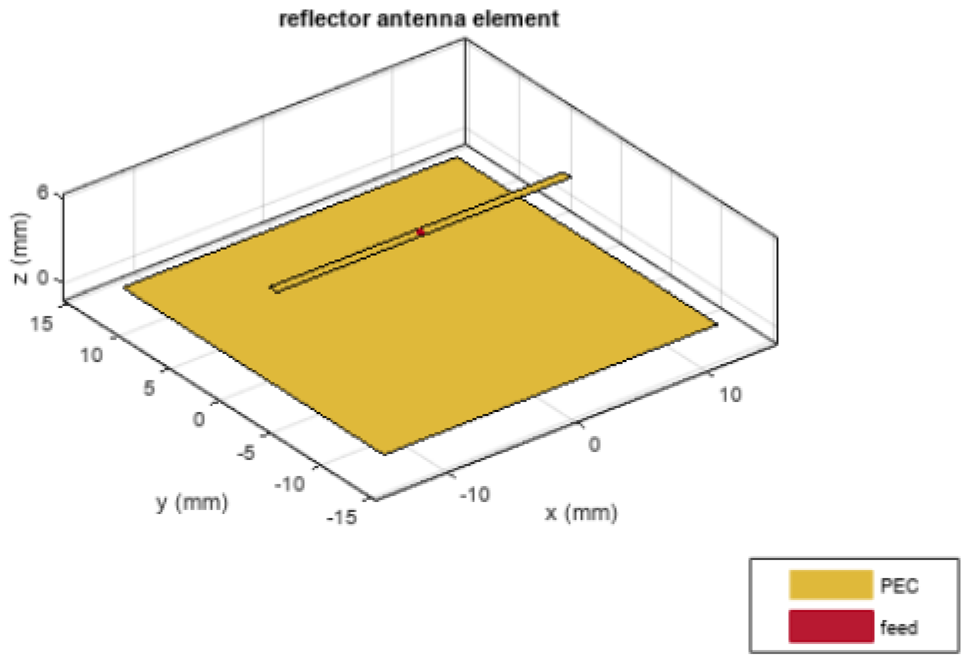
```
F0 = 5.8e9;

lambda = physconst("LightSpeed")/F0;

k = 2*pi/lambda;


phi_inc = 0;

theta_inc = -45:1:45;

elevation_inc = 90 + theta_inc;

radius_inc = 100*lambda;

[x_inc,y_inc,z_inc] = sph2cart(phi_inc*pi/180,elevation_inc*pi/180,radius_inc);

inc_loc = [x_inc' y_inc' z_inc'];


phi_obs = 0;

theta_obs = 20;

elevation_obs = 90 - theta_obs;

radius_obs = 100*lambda;

[x_obs,y_obs,z_obs] = sph2cart(phi_obs*pi/180,elevation_obs*pi/180,radius_obs);
```

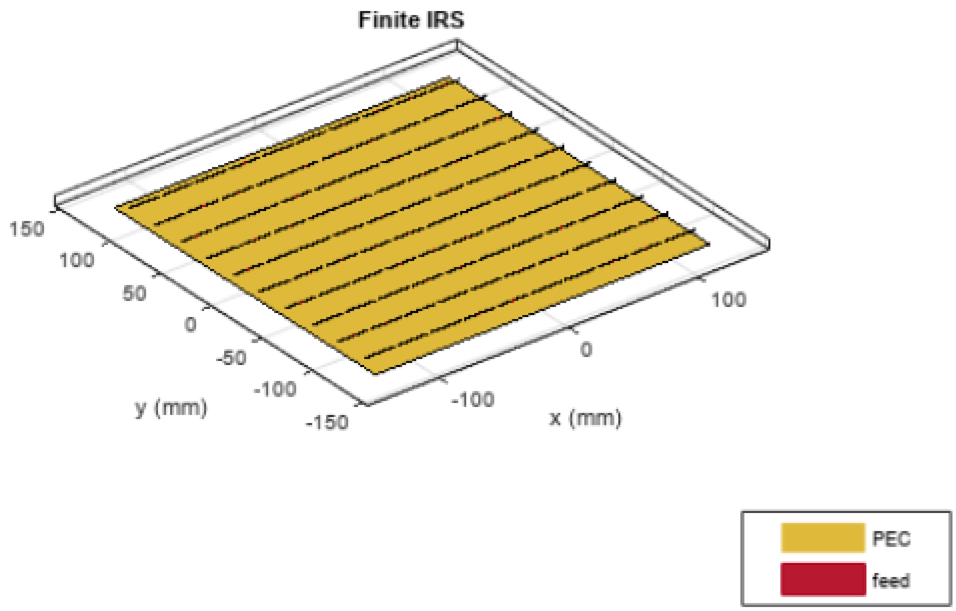
```
obs_loc = [x_obs, y_obs, z_obs];


rf = design(reflector,F0);
rf.Spacing = lambda/10;
rf.GroundPlaneLength = 0.5*lambda;
rf.GroundPlaneWidth = 0.5*lambda;
figure;
show(rf)


ifa = rectangularArray(Element==rf, Size==[10 10],...
   ColumnSpacing==rf.GroundPlaneLength,...
   RowSpacing==rf.GroundPlaneWidth);
figure;
show(ifa)
title("Finite IRS")


irs = infiniteArray(Element=rf);
irs.ScanAzimuth = phi_obs;
irs.ScanElevation = elevation_obs;
numSummationTerms(irs,20);
figure;
show(irs)
title("Infinite IRS")
```

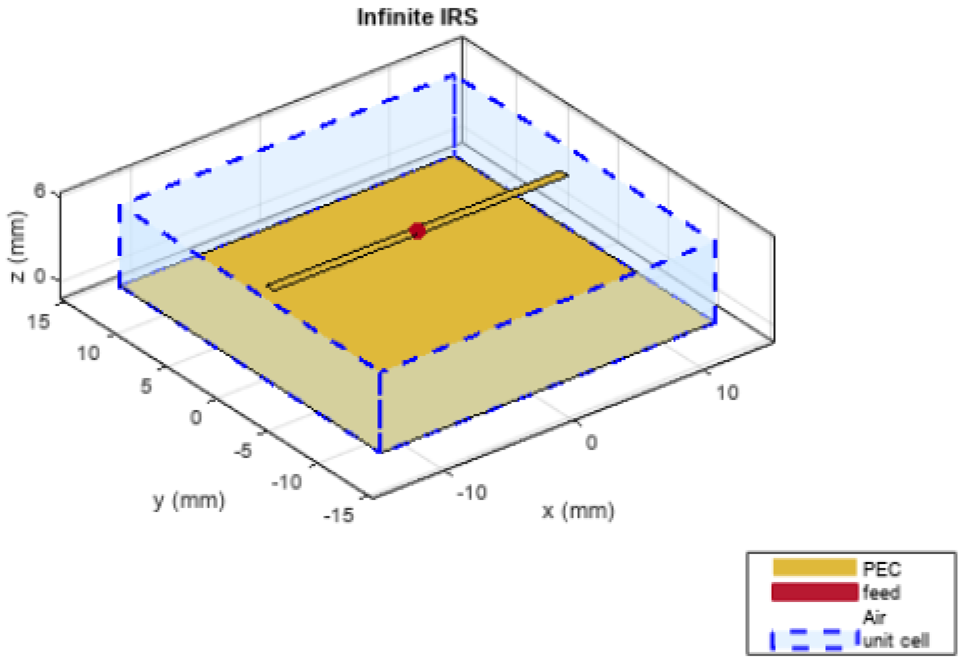
```
% Compute the Array factor
AF=hArrayFactorCalc(irs,F0);

MagReflection=zeros(1,numel(theta_inc));
PhaseReflection=zeros(1,numel(theta_inc));

for mm = 1:numel(theta_inc)

   % Construct a planeWaveExcitation object with the IRS as element
   [pw,pol,dir] = hcalcPlaneWaveIncidence(theta_inc(mm),phi_inc,irs);

   % Compute incident field upon the IRS
   Ein = pol;
   Einc = dot(Ein,pol/norm(pol));

   % Compute the outward scattered field from the IRS
   [Eo,~] = EHfields(pw,F0,obs_loc');
   Eo = Eo*AF;
   Eobs = dot(Eo,pol/norm(pol));

   % Compute the reflection coefficient of the IRS
   MagReflection(1,mm) = abs(Eobs/Einc);
```

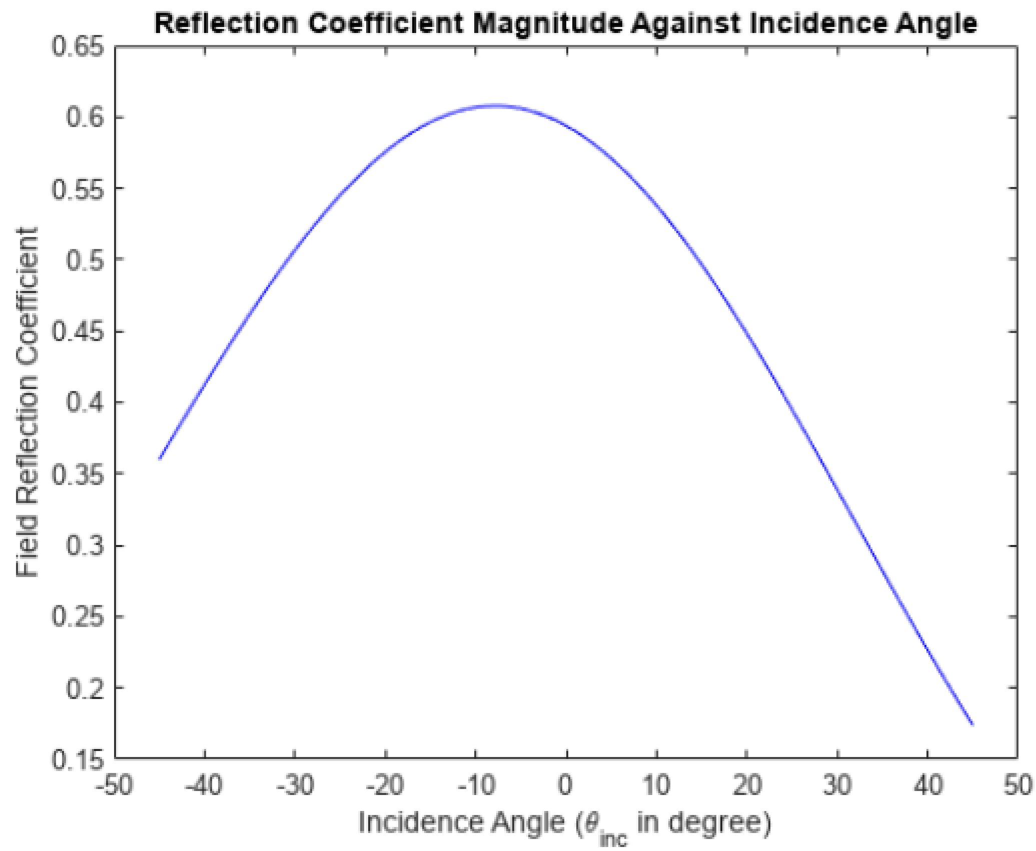
```
    PhaseReflection(1,mm) = (angle(Eobs/Einc))*180/pi;
end
figure;
plot(theta_inc,MagReflection,"b")
title("Reflection Coefficient Magnitude Against Incidence Angle")
xlabel("Incidence Angle (\theta_{inc} in degree)")
ylabel("Field Reflection Coefficient")

figure;
plot(theta_inc,PhaseReflection,"b")
title("Reflection Coefficient Phase Against Incidence Angle")
xlabel("Incidence angle (\theta_{inc} in degree)")
ylabel("Field Reflection Coefficient Phase")
```

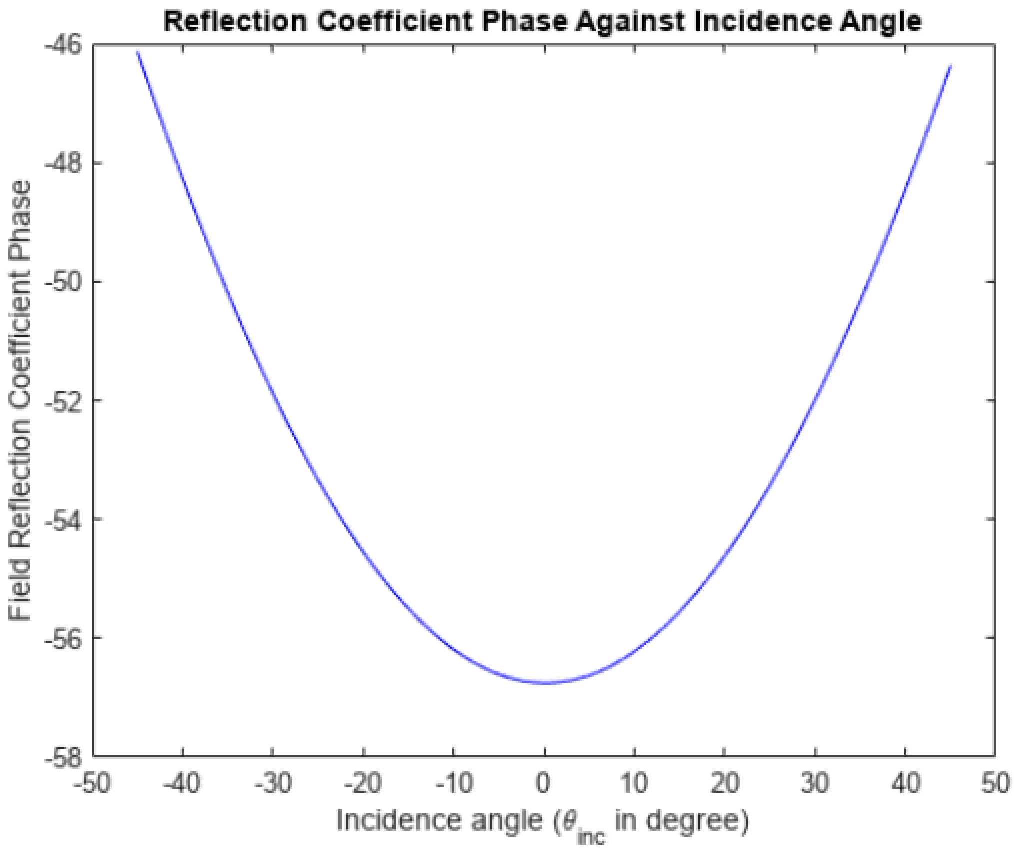
Result


reflector antenna element
z (mm)
6
0
15
10
5
0
-5
-10
-15
y (mm)
-10
0
10
x (mm)
PEC
feed


Finite IRS
150
100
50
0
-50
-100
-150
y (mm)
-100
0
100
x (mm)
PEC
feed


Infinite IRS
6
0
z (mm)
15
10
5
0
-5
-10
-15
y (mm)
-10
0
10
x (mm)
PEC
feed
Air
unit cell


Reflection Coefficient Magnitude Against Incidence Angle
Field Reflection Coefficient
Incidence Angle (θ_{inc} in degree)
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
-50
-40
-30
-20
-10
0
10
20
30
40
50


Reflection Coefficient Phase Against Incidence Angle
Field Reflection Coefficient Phase
-46
-48
-50
-52
-54
-56
-58
-50
-40
-30
-20
-10
0
10
20
30
40
50
Incidence angle (θinc in degree)

References

https://www.mathworks.com/help/antenna/ug/electromagnetic-analysis-of-intelligent-reflecting-surface.html?searchHighlight=Intelligent%20Reflecting%20Surfaces&s_tid=srchtitle_Intelligent%20Reflecting%20Surfaces_1&fbclid=IwAR0xDCkXauXC4nOKmG7L1L6cWFyjWvGIRHqN-4kW0Wu2hmvreIZ-fDvDER8