Tracing Path Gain to Measure Signal Strength from Diffraction

Christopher Leong (cleong3@hawaii.edu) and Matthew Sahara (saharama@hawaii.edu)

Department of Electrical Engineering

University of Hawai`i at Manoa

*Abstract*—This electronic document is a “live” template and already defines the components of your paper [title, text, heads, etc.] in its style sheet. *\*CRITICAL: Do Not Use Symbols, Special Characters, Footnotes, or Math in Paper Title or Abstract*. (*Abstract*)

Keywords—component, formatting, style, styling, insert (key words)

# Introduction

With the rise of wireless communication systems, attention must be given to

# Formulation

## To investigate the path gain along a two-dimensional (2D) street cross-section, a model must be defined. This model will account for an intersection. Because only diffraction is accounted for, only the corners of the intersection are necessary in the model.

Chart, line chart

Description automatically generated

Fig. 1: Modeled street intersection with path gain taken

on red and blue lines.

An omnidirectional transmitter is placed at the origin in Fig. 1. For the sake of wireless systems, the path gain gives crucial insight to the necessary signal from the transmitter. A possible lossy scenario can diminish the signal heavily. To investigate the path gain on the street with respect to distance, a line 500 m in length is stretched in two perpendicular directions, each line parallel to the walls of the street. Line AB is 20 m north of the green wall and Line CD is 30 m west of the purple and green walls depicted in Fig. 1. The path gain is calculated every 0.05 m.

To determine the path gain, the received fields from three sources must be considered: the incident field and the diffracted fields from the two corners. The incident field is given as

*ei(r) = e-jβr/r* (1)

where *r* is the distance from the transmitter to the receiver. The *β* represents

*β= 2πf/c* (2)

as *f* is the frequency of the transmitted field and *c* is the speed of light.

The diffracted field received is dependent on the distance from the transmitter to the diffraction corner, the distance from the receiver to the diffraction corner, and the angles from a designated 0-face to the direct rays as seen in Fig. 2.

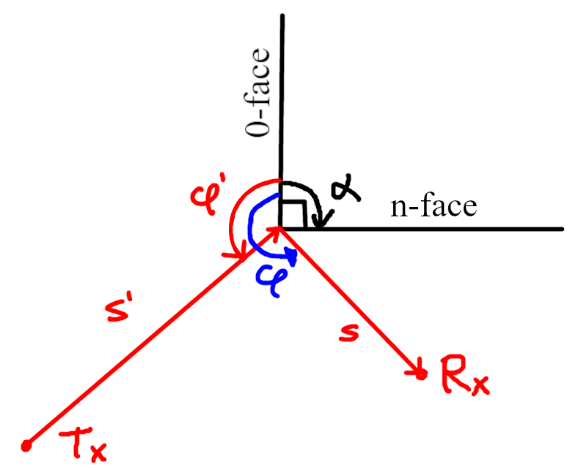


Fig. 2: Diffraction definitions.

The diffracted field is given by

(3)

where *λ* is the wavelength given by *c/f*, *s’* and *s* are the magnitudes of the distance vectors in Fig. 2, and *ds* is the diffraction constant dependent on *L*, *φ*, and *φ’* seen in Fig. 2. The parameter *ds* is calculated through a script provided by Dr. Zhengqing Yun. Parameter *L* is calculated by

(4)

and input into the script with *φ, φ’, α = 90,* and *n = 1.5*.

The total field *e(r)* is the sum of the incident field and the diffraction fields from each of the two corners. The path gain is calculated with

(5)

and measuring the path gain in dB results in

(6)

MATLAB is used to model the system by calculating the path gain along the lines every 0.05 m. The frequency is taken at 1GHz. The script used is in Appendix A.

# Results

The path gain along the defined lines in Fig. 1 was calculated and plotted in respect to the x-coordinate or y-coordinate for line AB and line CD, respectively. Line AB stretches from coordinates (0,70) to (500,70).

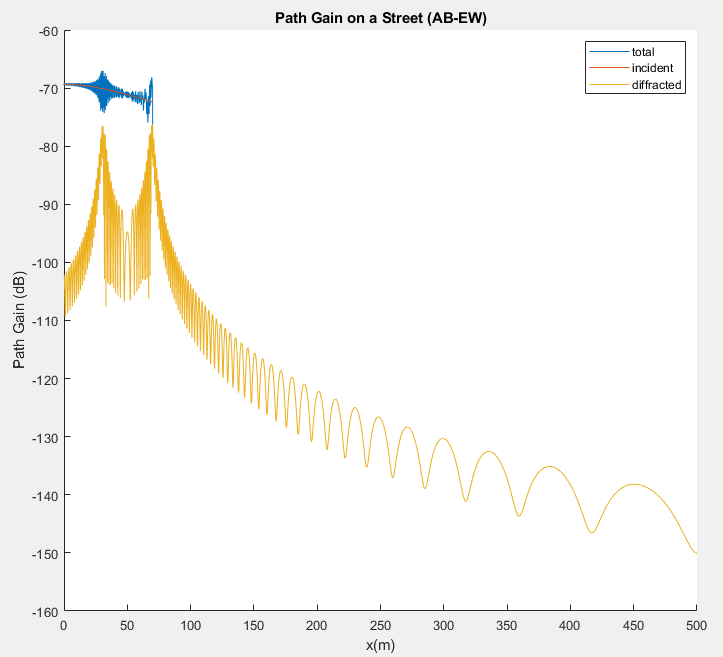


Fig. 3: Path gain along the line AB going east to west

Along the line AB from coordinates (0,70) to (70,70) as seen in Fig. 3, the frequency of the oscillations is high. Around *x* = 30, the amplitude of the oscillations stretches from -67 dB to -74 dB. From *x* = 70 on, the frequency of the oscillations and the magnitude of the signal begins to diminish exponentially, ending in the magnitude of -150 dB at *x* = 500.

Intrinsically this describes the signal to the receiver at its maximum from (0,70) to (70,70) near the intersection of the streets. As expected, the signal diminishes from a transmitter as distance increases from the intersection and the transmitter. Because the incident field is blocked by buildings from (70,70) onward, the signal at those points is attributed only by diffraction.

Line CD stretches from coordinates (20,0) to (20,500). Unlike line AB, it stretches with respect to the y-direction. The incident field from the transmitter is always in view with the points on this line.

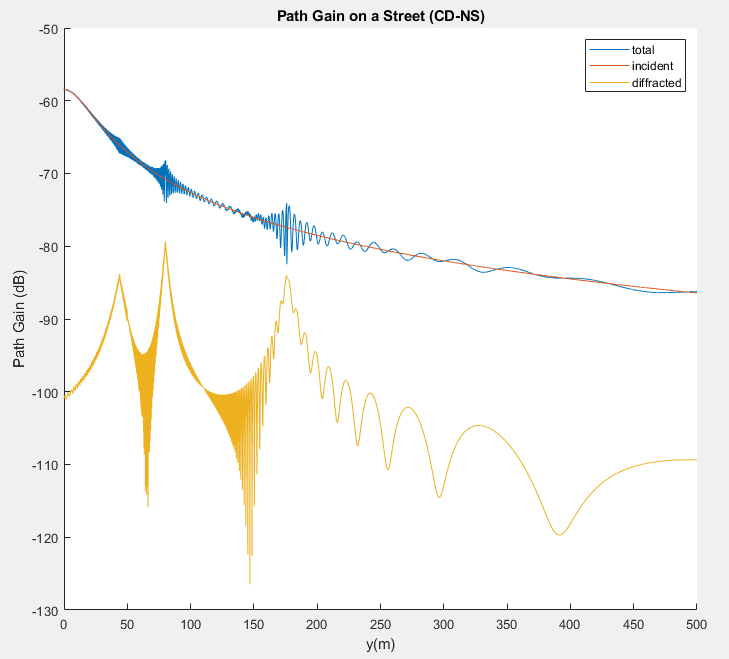


Fig. 4: Path gain along the line CD going north to south

Like the path gain on line AB, the signal experiences oscillations when moving from point C to point D and the oscillations’ frequency and magnitude diminish with the distance. The signal is at its maximum in the intersection of the two streets and diminishes with the distance from (20,0) to (20,500).

For both lines, the oscillations are largely attributed to diffraction from the two corners. In Fig. 3 and Fig. 4, the red incident field lines show that without diffracted fields, the resultant field would be exponential with no oscillations. Bringing diffracted fields into the equation adds oscillation to the incident signal. Higher peaks in the diffracted fields in Fig. 4 line up with higher amplitudes in the total field implying that diffraction is responsible for these larger amplitudes of the signal.

For comparison between the two lines, it is possible to check the methodology by referencing the intersecting point between the lines (20,70). The magnitude of the received signal at this point for line AB is -69.5980 dB while the magnitude for line CD is -69.6109, leaving a 0.0129 dB difference. This difference is minimal and may be attributed to errors in calculation.

# Conclusion

During this exercise, it is found that the signal diminishes with distance. Diffraction maintains a key part in

There are several advancements that can be made to this model to bring it closer to realism. One of these advancements is taking reflection into account, which would require the research of reflection coefficients for the properties of building materials. Taking the third dimension into consideration is another improvement that can be made to this model.

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

# Conclusion

present them within parentheses. Do not label axes only with units. In the example, write “Magnetization (A/m)” or “Magnetization {A[m(1)]}”, not just “A/m”. Do not label axes with a ratio of quantities and units. For example, write “Temperature (K)”, not “Temperature/K”.

##### Acknowledgment *(Heading 5)*

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

##### References

The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use “Ref. [3]” or “reference [3]” except at the beginning of a sentence: “Reference [3] was the first ...”

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors’ names; do not use “et al.”. Papers that have not been published, even if they have been submitted for publication, should be cited as “unpublished” [4]. Papers that have been accepted for publication should be cited as “in press” [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

1. G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*
2. J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
3. I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.
4. K. Elissa, “Title of paper if known,” unpublished.
5. R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.
6. Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].
7. M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

**IEEE conference templates contain guidance text for composing and formatting conference papers. Please ensure that all template text is removed from your conference paper prior to submission to the conference. Failure to remove template text from your paper may result in your paper not being published.**

##### Appendix A. Matlab Script

close all; clear;

figure; hold on; grid on;

%plot street intersection

plot([0, 500], [70, 70], '-o')

plot([20, 20], [0, 500], '-o')

plot(0,0, 'o')

plot([50, 50, 600], [600, 110, 110], '-o')

plot([50, 50, 600], [-10, 50, 50], '-o')

xlabel('x(m)'); ylabel('y(m)');

title('Street');

%whole parameters

wavelength = 3\*10^8/1000000000; %c/f

beta = 2\*pi/wavelength;

Q1x = 50; Q1y = 50; Q2x = 50; Q2y = 110;

%AB direct field

ab = [0:.05:500;70\*ones(1,10001)];

RAB = sqrt(ab(1,:).^2 + ab(2,:).^2);

incidAB = exp(-1i\*beta.\*RAB)./RAB;

incidAB(1401:end) = 0; %50/.05 = 1000

%diff1 AB- diffraction due to Q1

sp = sqrt(50^2 + 50^2); %calculate distance from transmitter to corner

s = sqrt((Q1x - ab(1,:)).^2+(Q1y - ab(2,:)).^2); %calculate distance from corner to receiver

L = 1/wavelength.\*sp.\*s./(s+sp); %calculate L

v1 = [zeros(1,10001);-1\*ones(1,10001)]; phip = 45; %define wall unit vector, phi'

v2 = [ab(1,:) - 50; ab(2,:) - 50]./s; %calculate unit vectors from corner to receiver

phi = acos(dot(v1,v2))\*180/pi; %find angle

phi(1001:end) = 360 - phi(1001:end); %change negative (=pos) cosines to positives

%take diffraction constant from function

for n = 1:1:length(phi)

[ds,dh] = wdc(L(n),phi(n),phip,90,1.5);

dsAB(n) = ds;

end

%calculate path gain based on summed matrix field

diff1AB = -sqrt(wavelength).\*dsAB./sqrt(sp.\*s.\*(sp+s)).\*exp(-1i\*beta.\*(sp+s));

%diff2 AB - diffraction due to Q2

sp = sqrt(50^2 + 110^2);

s = sqrt((Q2x - ab(1,:)).^2+(Q2y - ab(2,:)).^2);

L = 1/wavelength.\*sp.\*s./(s+sp);

v1 = [zeros(1,10001);ones(1,10001)];

v2 = [ab(1,:) - 50; ab(2,:) - 110]./s;

phip = acos(dot([50,110]/sqrt(110^2+50^2),[0,1]))\*180/pi;

phi = acos(dot(v1,v2))\*180/pi;

phi(1001:end) = 360 - phi(1001:end);

%take diffraction constant from function

for n = 1:1:length(phi)

[ds,dh] = wdc(L(n),phi(n),phip,90,1.5);

dsAB(n) = ds;

end

diff2AB = -sqrt(wavelength).\*dsAB./sqrt(sp.\*s.\*(sp+s)).\*exp(-1i\*beta.\*(sp+s));

PGAB = (wavelength/4/pi)^2 .\* abs(incidAB + diff1AB + diff2AB).^2;

PGAB\_d = (wavelength/4/pi)^2 .\* abs(diff1AB + diff2AB).^2;

PGAB\_i = (wavelength/4/pi)^2 .\* abs(incidAB).^2;

%CD

cd = [20\*ones(1,10001);0:.05:500];

%CD direct field

RCD = sqrt(cd(1,:).^2 + cd(2,:).^2);

incidCD = exp(-1i\*beta.\*RCD)./RCD;

%diff1 CD- diffraction due to Q1

sp = sqrt(50^2 + 50^2);

s = sqrt((Q1x - cd(1,:)).^2+(Q1y - cd(2,:)).^2);

L = 1/wavelength.\*sp.\*s./(s+sp);

v1 = [zeros(1,10001);-1\*ones(1,10001)]; phip = 45;

v2 = [cd(1,:) - 50; cd(2,:) - 50]./s;

phi = acos(dot(v1,v2))\*180/pi;

phi(1001:end) = 360 - phi(1001:end);

%take diffraction constant from function

for n = 1:1:length(phi)

[ds,dh] = wdc(L(n),phi(n),phip,90,1.5);

dsCD(n) = ds;

end

diff1CD = -sqrt(wavelength).\*dsCD./sqrt(sp.\*s.\*(sp+s)).\*exp(-1i\*beta.\*(sp+s));

%diff2 CD - diffraction due to Q2

sp = sqrt(50^2 + 110^2);

s = sqrt((Q2x - cd(1,:)).^2+(Q2y - cd(2,:)).^2);

L = 1/wavelength.\*sp.\*s./(s+sp);

v1 = [zeros(1,10001);ones(1,10001)];

v2 = [cd(1,:) - 50; cd(2,:) - 110]./s;

phip = acos(dot([50,110]/sqrt(110^2+50^2),[0,1]))\*180/pi;

phi = acos(dot(v1,v2))\*180/pi;

phi(1001:end) = 360 - phi(1001:end);

%take diffraction constant from function

for n = 1:1:length(phi)

[ds,dh] = wdc(L(n),phi(n),phip,90,1.5);

dsCD(n) = ds;

end

diff2CD = -sqrt(wavelength).\*dsCD./sqrt(sp.\*s.\*(sp+s)).\*exp(-1i\*beta.\*(sp+s));

%calculate path gain from summed matrices

PGCD = (wavelength/4/pi)^2 .\* abs(incidCD + diff1CD + diff2CD).^2;

PGCD\_i = (wavelength/4/pi)^2 .\* abs(incidCD).^2;

PGCD\_d = (wavelength/4/pi)^2 .\* abs(diff1CD + diff2CD).^2;

%plot path gain from east to west

figure; hold on;

PGABdB = 10\*log10(PGAB);

PGAB\_idB = 10\*log10(PGAB\_i);

PGAB\_ddB = 10\*log10(PGAB\_d);

plot(ab(1,:), PGABdB,'DisplayName','total');

plot(ab(1,:), PGAB\_idB,'DisplayName','incident');

plot(ab(1,:), PGAB\_ddB,'DisplayName','diffracted');

legend

title('Path Gain on a Street (AB-EW)')

xlabel('x(m)');

ylabel('Path Gain (dB)');

%plot path gain from north to south

figure; hold on;

PGCDdB = 10\*log10(PGCD);

PGCD\_idB = 10\*log10(PGCD\_i);

PGCD\_ddB = 10\*log10(PGCD\_d);

plot(cd(2,:), PGCDdB,'DisplayName','total');

plot(cd(2,:), PGCD\_idB,'DisplayName','incident');

plot(cd(2,:), PGCD\_ddB,'DisplayName','diffracted');

legend

title('Path Gain on a Street (CD-NS)')

xlabel('y(m)');

ylabel('Path Gain (dB)');