Antennas Project

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Half-Wavelength Dipole design & simulation

I. *Introduction:*

An antenna is a conductive transducer that converts between electrical power and electromagnetic waves. In this paper, we are tasked with designing a transmit and receive antenna platform. The antenna operates at 100mW of power and is to be placed in the classroom. The operational frequency of the antenna is 4.23 GHz. The antenna is to provide minimum coverage within the classroom, defined as 10mW of received power.

The half wavelength dipole antenna is chosen as it has the additional radiator that generates a synthetic ground plane, eliminating the need of a physical ground plane. Furthermore, it's chosen for its high efficiency. Its basic construction is of two transmission lines terminated by an open circuit, bend at 90 degrees each as can be seen in the figure below.

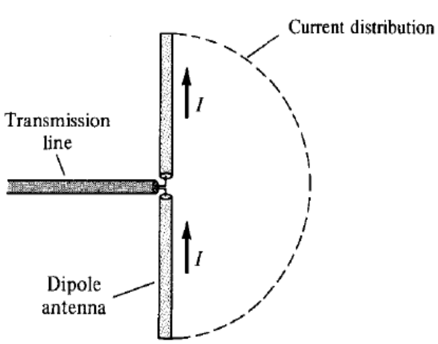

Figure 1: Dipole antenna construction from open circuit terminated transmission lines [1].

The sinusoidally oscillating current distribution causes fields to propagate from the antenna.

The software used to design the antenna is 4NEC2, although MATLAB will be used to verify the design and provide complementary data that 4NEC2 may not provide. The site survey will be performed using GO3D software, through which the dimensions and geometry of the classroom will be considered to produce the standing wave pattern within the room.

II. *Antenna Design &Analysis*

Firstly, the length of the antenna must be selected as half of the wavelength, and is found to be:

$$L = \frac{\lambda}{2} = \frac{c}{2\,f} = \frac{3x10^8}{2(4.23x10^9)} = 35.46\,mm$$

The radius is selected to be R = 1.418mm. The segment length in 4NEC2 is computed as 6% of wavelength and is found to be 4.255mm. The ratio is then computed as:

$$Ratio = \frac{Segment\ Length}{Wire\ Radius} = 3$$

The ratio indicates the need for an EK card [3] to be enabled in the software, as can be seen in appendix A. This enables the extended thin-wire kernel. The number of segments used is 9, hence the feed point is to be placed in the middle of segment 5. The feed is a voltage source, of 1V. The antenna is specified to be stainless steel, with conductivity of 1.39e08. Finally, the ground plane is specified to be SomNec ground, which simulated the environment of buildings in cities. It provides a conductance of 1e-3 and relative permittivity of 5. The antenna is shown in the figure below with its current distribution.

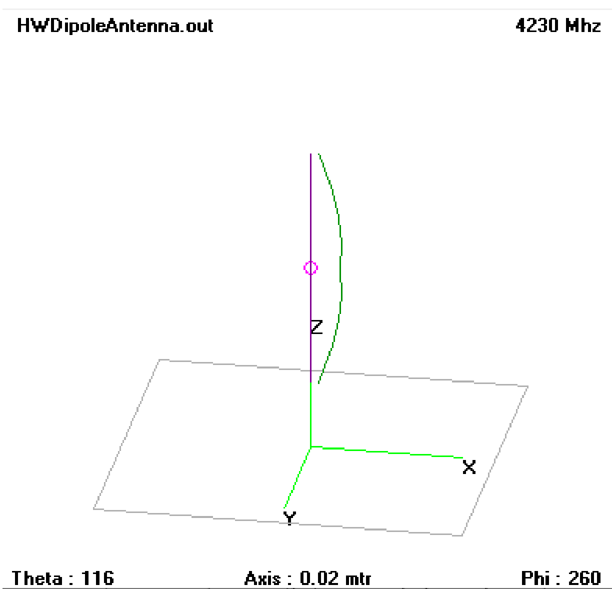

Figure 2: The dipole antenna in 4NEC2 software shown in purple. The tapered current distribution along the dipole is shown as a green curve.

The resulting 3-D far field pattern is shown in the figure below.

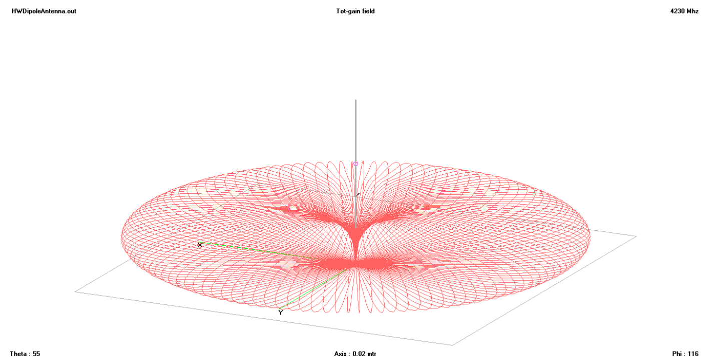

Figure 3: Radiation pattern of total gain of half-wave dipole antenna designed.

The theta and phi cuts are shown in the figures below.

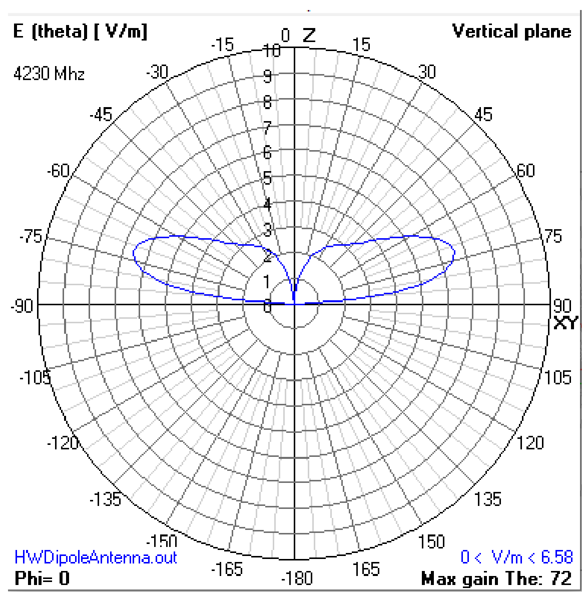

Figure 4: E-theta field on Phi = 0 plane.

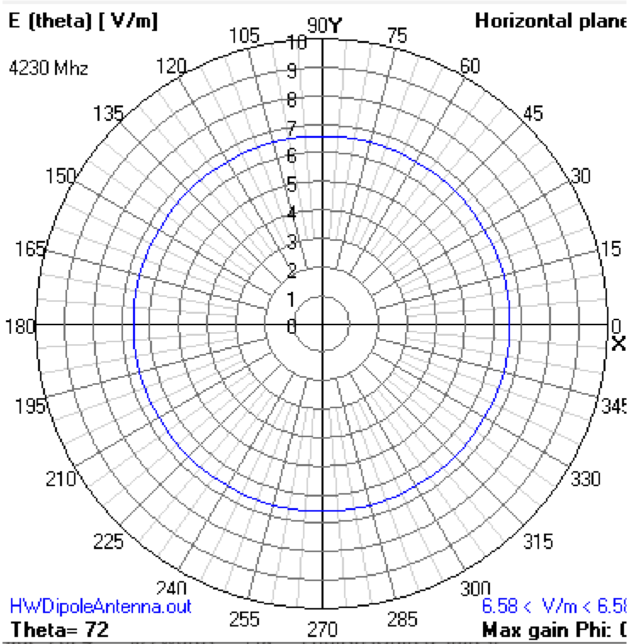

Figure 5: E-theta field on theta = 72 plane.

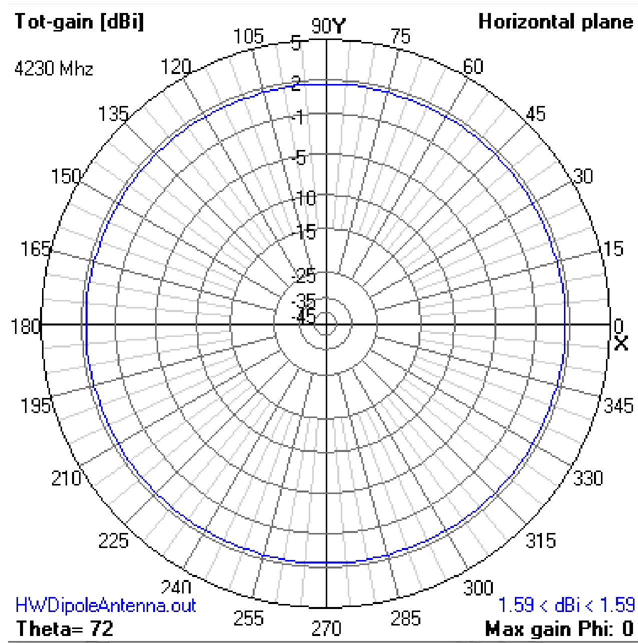

Figure 7: Total gain field in the Theta = 72 plane.

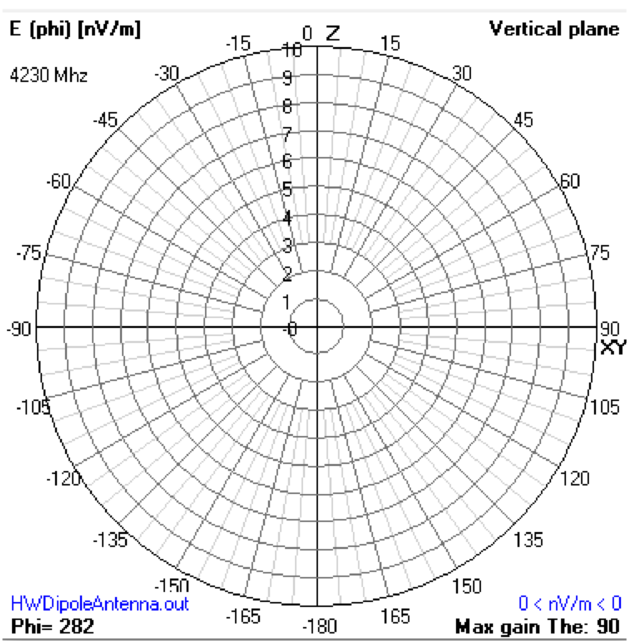

Figure 6: E-phi field on the Phi = 282 plane. Note that as the E-phi field is 0 for both phi and theta cuts, the theta cut wasn't included.

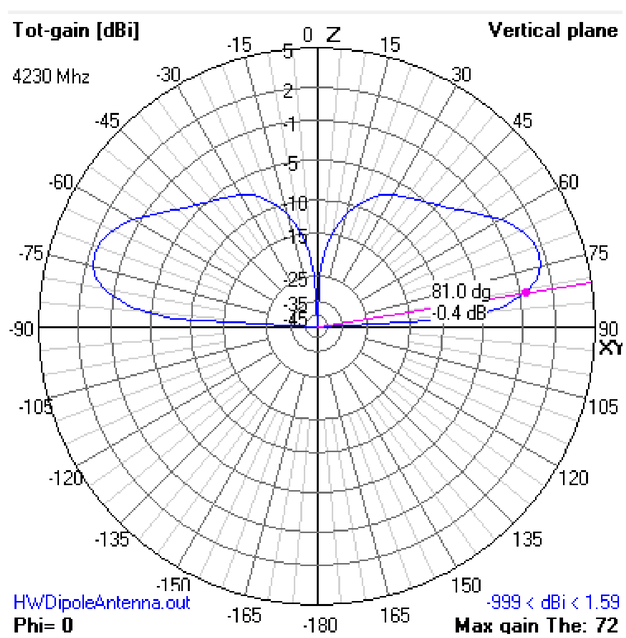

Figure 7: Total gain field in the Phi = 0 plane. The HPBW is approximately indicated by the purple line.

The HPBW is defined as the point at which the power of the field is at half of its max. It provides a loose measure of the directivity of the antenna. The HPBW is bound by two points. The two points are (82 degrees, -1.0 dB) & (83 degrees, -1.76 dB). Interpolating these points to find the -3dB point from the max (1.59dB). It is found to be 81.83 degrees, which is approximately close to the 78 degrees theoretical value. The mismatch is due to the SomNec ground. The characteristics of the surrounding media cause the discrepancy. Furthermore, varying parameters barely changes the directivity as it is expected to be approximately constant.

The figure below displays the smith chart of our design, highlighting SWR & reflection loss.

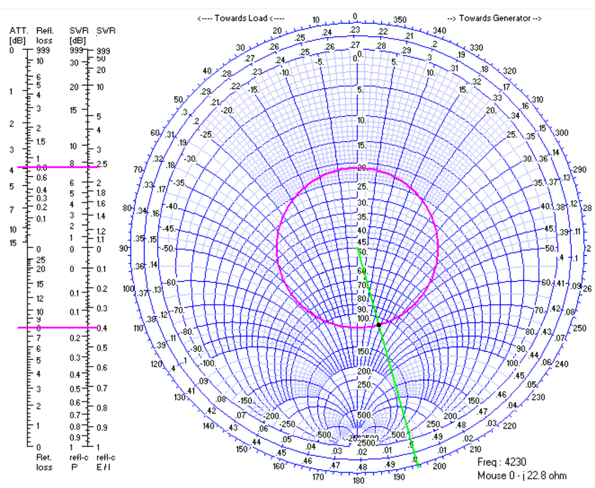

Figure 8: Smith chart of current design. SWR and Reflection loss are seen on the left.

The input impedance measures the resistive and reactive characteristics of the antenna at the input or feed point. It is 116 + j28.8 ohms. The input voltage is 11.1 V with a current of 0.09 – j 0.02A. This results in 1W of input power to the antenna. As the software doesn't allow inputting power less than 1W, the voltage is divided by 10 to result in 100mW of input power to the antenna. Moreover, the standing wave ratio is found to be 2.49. Optimizing the length of the antenna to 31.1 mm improved the SWR to 1.47.

The MATLAB simulations are input the same parameters as those input to 4NEC2. The results are relatively similar, the figures for impedance and S parameters are shown in the figures below. The S parameters provides a measure of the reflection loss.

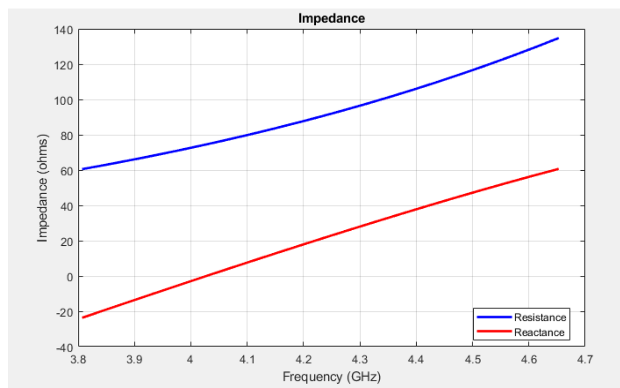

Figure 9: Input impedance of the antenna as a function of frequency.

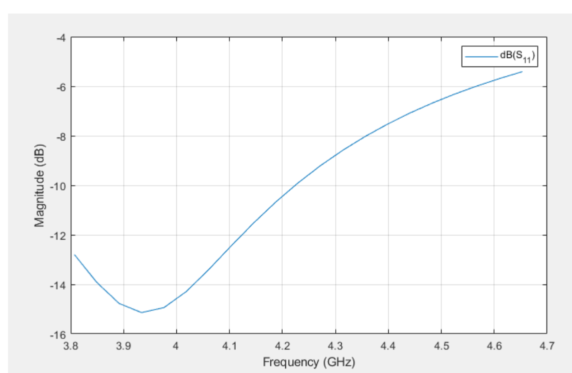

Figure 10: S-parameter S11 as a function of frequency. This parameter provides the relationship between port 1 and itself (Reflections/Loss).

The polarization of the antenna is linear. This may pose an issue if the receivers' antenna is also linearly polarized and oriented perpendicularly to the transmit antenna. Most modern antennas employ designs that receive in all orientations; thus, this shouldn't be an issue.

III. Site Survey & Simulations

The GO3D code can be found in the appendix B. The room dimension schematic can be seen in the figure below.

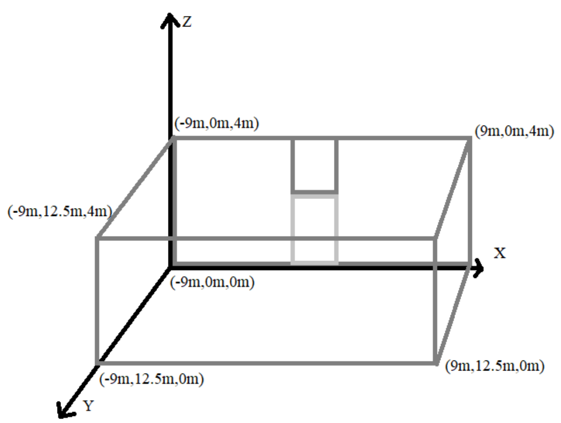

Figure 11: 3D Room geometry showcasing door (light grey) & 6 walls that are to be constructed.

The import source doesn't correctly work with the 4NEC2 output, so the half wave dipole source provided by GO3D was used. Firstly, the frequency is set to 4230 MHz & source power to 100mW. The coordinates of the room are chosen such that the origin point is located at the bottom center point of the door. The half wave source dipole is then placed above the door at coordinate points (0.56, 0.56, 3.7164), oriented in the positive x direction. The threshold is the power below which the software will discard a simulated ray. It is optimized based on my computer's capabilities and is set to -12dB.

Next, the Material definitions for constructing objects is tackled. The figure below shows the material definition and their respective parameters.

```
C Materials for building walls:
C           Name       epsr       sigma (mS/m)     mur
MATERIAL    Space      1.0        0.0              1.
MATERIAL    Metal      1.0        1.E7             1.
MATERIAL    Brick      5.1       10.               1.
MATERIAL    Concrete   6.1       60.1              1.
MATERIAL    Plaster    2.9       11.6              1.
```

Figure 12: GO3D code snippet showcasing the material definitions. The parameter columns showcase relative permittivity, conductance, and relative permeability. The rest of the code can be found in appendix B.

The materials are used to construct wall objects, from which the floor plan will be made. A Door is created from metal with a thickness of 9cm. A 3 layered wall of plaster, brick and plaster of total thickness 48cm is used to create the walls. To improve the field profile of the antenna in the room, back reflectors above the antenna on the ceiling and behind the antenna on the wall are created. They serve to improve the reflection of back-propagating waves, into the classroom. The floor plan can be seen in the figure below.

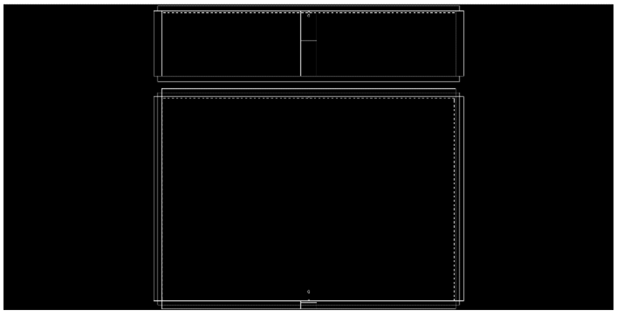

Figure 13: Floor plan of the simulated classroom. The top figure showcases an X-Z plane view and the bottom figure showcases a X-Y plane view. The door can be seen as a rectangle, and the antenna as a dot above the door.

A grid receiver is used to plot the fields in the entire room in an X-Y planar cut. The typical height for a student laptop operating on a classroom desk is z = 0.9m. The fields strength at various heights are shown in the figure below.

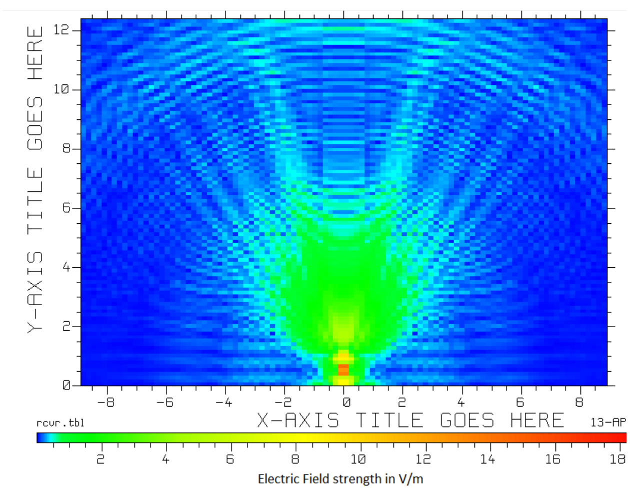

Figure 14: Electric field strength on X-Y plane of classroom at height z = 3.7m.

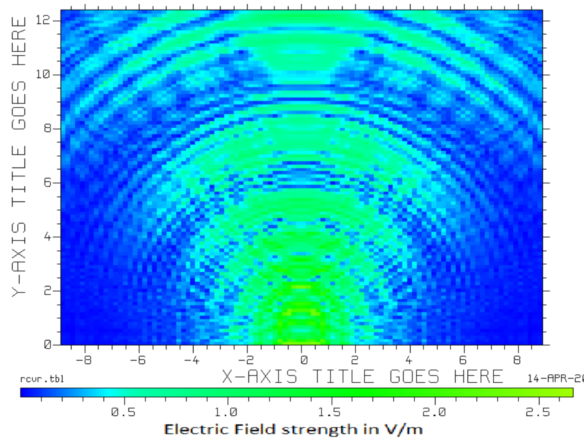

Figure 15: Electric field strength on X-Y plane of classroom at height z = 1.7m.

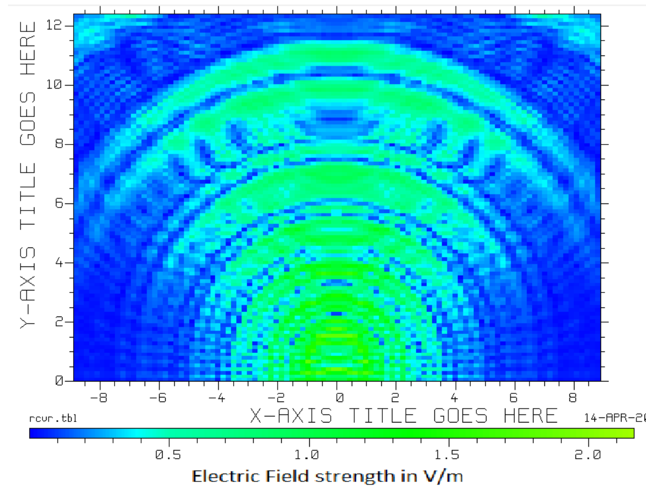

Figure 16: Electric field strength on X-Y plane of classroom at height z = 0.9m.

The minimum received power is 10mW, converting to Electric field strength:

$$E = \sqrt{\frac{\eta}{2\pi}P} = 0.7746\ V/m\ ;\ [7]$$

$$\eta = 377.7\ ohm$$

Thus, 0.7746 V/m is the minimum required field strength to receive coverage. As can be seen in the figures above, there is roughly enough coverage in the room. There are a few dead spots, specifically the two backside corners of the room. Optimal coverage is received at the height of the antenna, as can be seen in figure 14. The height of the antenna is thus changed to above the door at height z = 2.3m. The figure below showcases the field strength at that height.

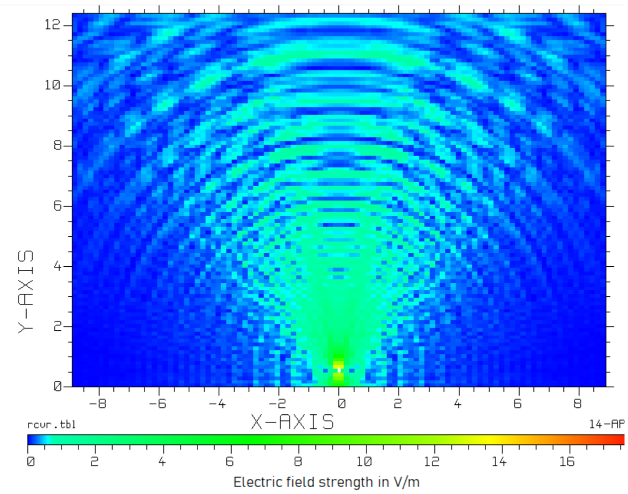

Figure 17: Electric field strength on X-Y plane of classroom at height z = 2.3.

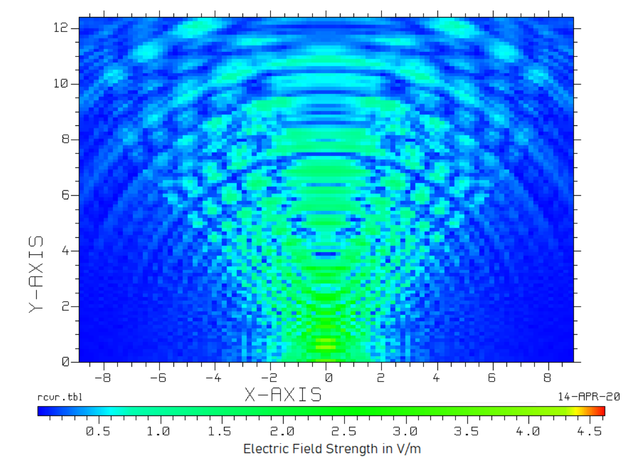

Figure 18: Electric field strength on X-Y plane of classroom at height z = 0.9.

IV. <u>*Parts Listing*</u>

This section presents the item's required for purchase to create the system described by this report. The various vendors for these items are found in appendix C.

- Stainless steel metal rod:
  - L = 31.1 mm
  - R = 1.4183 mm
- Polytetrafluoroethylene (PTFE) coating:
  - To coat the entire antenna, including feed & end points.
- 4.23 Ghz Circulator.
- 2 m of Stainless-steel wire:
  - Used to connect coaxial cable to the antenna.
  - One wire is used for the core of the coaxial, and the other for the cladding.
- 75ohm Coaxial cable.

V. <u>*Conclusion*</u>

The half-wave dipole antenna has a slightly high input impedance, which may cause an issue when connecting to the coaxial cable. Further impedance matching is required there.

Limitations include the capabilities of the computer that's running the simulation.

More processing power would yield more accurate and precise results.

The half-wave dipole antenna provides decent coverage in most of the room, with a few dead spots. This coverage was tremendously improved by including a back reflector, as dipole antennas are omnidirectional. This helps improve the reflection of the back-propagating waves. The dead spots are in the back corners of the room, as that's where the antenna is oriented towards. Providing coverage to these dead spots would require another antenna.

VI. Appendix

A. 4NEC input file:

```
CM ECSE 405:Antennas Project
CM Ameer Ibrahim Osman 260682723
CE
GW      1       9       0.0     0.0     0.01004 0.0     0.0     0.0455  0.00142
GE      0
EK      0
LD      5       0       0       0       58000000        0
EX      0       1       5       0       1       0
GN      2       0       0       0       5       1.e-3
FR      0       1       0       0       4230    0
EN
```

B. GO3D Code:

```
C ECSE 405: Project
C
C The frequency:
FREQUENCY      4230.  MHz
C
C The source power in milliwatts:
SOURCE_POWER  100.
C
C The location of the source:
POINT xmitter  0.0 0.5636 3.7164
SOURCE_LOCATION xmitter
C
C Half-wave dipole source:
DIPOLE_SOURCE  1.  0.  0.
C
C Imported source:
C IMPORTED_SOURCE  HW_Dipole_V3.sol
C
C The threshold field strength in dB below the "isotropic level":
ETHRESHOLD  -12.
C
C Materials for building walls: (850 MHz)
C           Name       epsr       sigma (mS/m)   mur
MATERIAL    Space      1.0        0.0            1.
MATERIAL    Metal      1.0        1.E7           1.
MATERIAL    Brick      5.1       10.             1.
MATERIAL    Concrete   6.1       60.1            1.
MATERIAL    Plaster    2.9       11.6            1.
C
C Wall construction definitions:
C         Name            type      material thickness (cm)
WALL_TYPE MetalDoor       SOLID     Metal      9
C         Name            type  layers  layer material and layer thickness
WALL_TYPE BrickPlaster  LAYERED 3 Plaster 4. Brick 40. Plaster 4.
```

```
C Define the floor plan:
C
C Vertical = Y ; Horizontal = X; Height = Z;
C Wall left of door(8.5m x 40cm x 4m):
POINT  1          -9.00   -0.24    0.00
POINT  2t          -0.5   -0.24    4.00
DEFINE_WALL 1 2t  BrickPlaster

C Wall Right of door (8.5m x 40cm x 4m):
POINT  1t          0.5   -0.24    0.00
POINT  2           9.0   -0.24    4.00
DEFINE_WALL 1t 2  BrickPlaster

C Wall Above the door (1m x 40cm x 1.8m):
POINT  11          -0.5   -0.24    2.20
POINT  12t          0.5   -0.24    4.00
DEFINE_WALL 11 12t  BrickPlaster

C Wall 2 (40cm x 12.5m x 4m):
POINT  3           9.24    0.00    0.00
POINT  4t          9.24    12.5    4.00
DEFINE_WALL   3  4t  BrickPlaster

C Wall 3 (18m x 40cm x 4m):
POINT  5           9.00    12.74   0.00
POINT  6t         -9.00    12.74   4.00
DEFINE_WALL   5  6t  BrickPlaster

Wall 4 (40cm x 12.5m x 4m):
POINT 7          -9.24    12.50   0.00
POINT 8t         -9.24    0.000   4.00
DEFINE_WALL  7 8t  BrickPlaster
```

```
C Door At Wall 1 (1m x 9cm x 2m) (Surf at y = 0m):
POINT 9          -0.50    -0.045  0.00
POINT 10t         0.50    -0.045  2.20
DEFINE_WALL  9 10t MetalDoor

C Back Reflectors

POINT br3        0.0175  0.0455  3.965
POINT br4        -0.0175 0.0455  3.995
DEFINE_WALL br3 br4 MetalDoor

POINT br5        0.0175  12.465  3.955
POINT br6        -0.0175 12.495  3.955
DEFINE_WALL br5 br6 MetalDoor

C

C Define the floor material and thickness in cm:
FLOOR   Concrete   30.
C Define the ceiling material, thickness in cm, and height in m:
CEILING Concrete   30.  4.00


C Grid Rx
POINT grid1      -8.9     0.0     3.9
POINT grid2       8.9     12.4    3.9
RCVRGRID         grid1 grid2      5.0

RPLFILE R
C TBLFILE

C End of File
```

C. Vendors list

a. Stainless-steel rod: https://www.grainger.com/category/raw-materials/stainless-steel/stainless-steel-rod-stock

b. PTFE: https://www.globalindustrial.ca/p/outdoor-grounds-maintenance/degreasers-lubricants/supplies/ptfe-sprayheavy-coat-16oz-aerosol-12-case-17080?infoParam.campaignId=T9F&gclid=CjwKCAjwvtX0BRAFEiwAGWJyZMOuNrMOT-WU_z0027QqVJSgHCQS15XFWCnIqfhb6ywWkx7w-aOk2RoCk08QAvD_BwE

c. 4.23 Ghz Circulator: https://www.digikey.ca/product-detail/en/l3-technologies,-inc,-narda-miteq/4913/1949-1117-ND/9093022?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=Google%20Smart%20Shopping_RF%2FIF%20and%20RFID&utm_term=&productid=9093022&gclid=CjwKCAjwvtX0BRAFEiwAGWJyZIYocuLrIHkTkDbSWD-AE_pNm6rhWJot5G5NFrKVSB4LBLO_Nn76BBoCNZQQAvD_BwE

d. 75 Ohm Coaxial cable: https://www.amazon.com/Digital-Shielded-Continuous-Compression-F-Connectors/dp/B015US5OG6/ref=sr_1_2?dchild=1&keywords=coax+cable&qid=1586846540&sr=8-2

VII. *References*

[1] Lodro, Mir. (2016). Antennas and Wave Propagation.

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Youtube, Mobilefish.com, www.youtube.com/watch?v=cUVXKYIe004&fbclid=IwAR08kymKox2trjKZl5VAyumTyJjNG RTOEc8miRkvFHur-xQAgftcN8peUII.

[4]https://myelectrical.com/notes/entryid/177/material-properties

[5]https://www.ifm.com/img/dialectric_constants.pdf

[6]https://www.tutorialspoint.com/antenna_theory/antenna_theory_half_wave_dipole.htm

[7] Trueman, Christopher W. "User's Guide for Program GO_3D, Version 1K." November 16, 1998, Electromagnetic Compatibility Laboratory Concordia University,users.encs.concordia.ca/~trueman/GO_3D/Guide.htm?fbclid=IwAR1j6LyHvTJHDdFFlfgCUaMRKWFbro28BEqlGSGqdMLZDOPvekRm10XwDLg.

[8] Gunthard Kraus " Simulation of Wire Antennas using 4NEC2" August 15, 2010, Oberstudienrat, Elektronikschule Tettnang, Germany,https://www.qsl.net/4nec2/Tutorial_4NEC2_english.pdf

[9] 4NEC2 Software. http://www.pa3kj.com/nec-archives/

[10] MATLAB Antenna Toolbox. https://www.mathworks.com/help/antenna/