Laboratory Oriented Project

Second Semester 2019 - 2020

Computational Electromagnetics FDTD Analysis

Under the guidance of Dr. Praveen Kumar A. V.

Utsav Akhaury - 2016B5A80684P

Objectives

To -

- Model end-to-end transmission microstrip lines
- Illuminate the source at one port and receive the signal at the other port
- Implement the FDTD algorithm for solving E and H at every point in the grid
- Plot the voltage & current at both ends versus time
- Analyse the corresponding plots in frequency domain (FFT)
- Check whether the peak frequency at both ends match with each other
- Observe and compare results for different cases

FDTD Algorithm

- Time Domain Algorithm
- Taylor Series Approximation of Maxwell's Curl equations

$$\nabla \times E = -\mu \frac{\partial H}{\partial t} \qquad \nabla \times H = \varepsilon \frac{\partial E}{\partial t}$$

$$\frac{\partial H_x}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_y}{\partial z} - \frac{\partial E_z}{\partial y}\right) \qquad \frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z}\right)$$

$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_z}{\partial x} - \frac{\partial E_x}{\partial z}\right) \qquad \frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x}\right)$$

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$$\frac{\partial F(x,t)}{\partial x} \approx \frac{\left(F(x+\Delta x,t)-F(x-\Delta x,t)\right)}{2\Delta x}$$

$$= \frac{\left(F(i+1,n)-F(i-1,n)\right)}{2\Delta x} = \frac{\left(F^{n}(i+1)-F^{n}(i-1)\right)}{2\Delta x}$$

$$\frac{\partial F(x,t)}{\partial t} \approx \frac{\left(F(x,t+\Delta t)-F(x,t-\Delta t)\right)}{2\Delta t}$$

$$= \frac{\left(F(i,n+1)-F(i,n-1)\right)}{2\Delta t} = \frac{\left(F^{n+1}(i)-F^{n-1}(i)\right)}{2\Delta t}$$

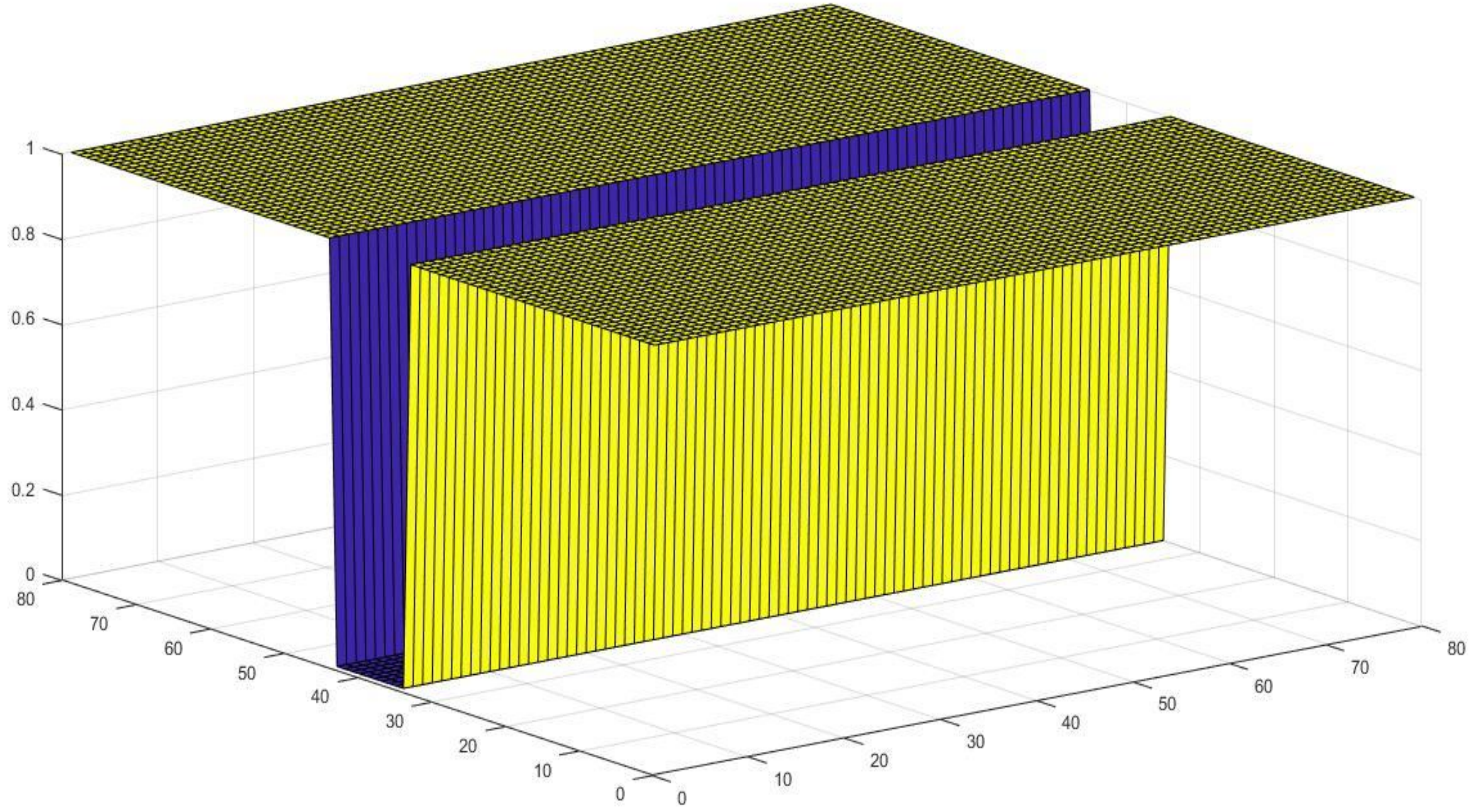
$$\frac{E_x^{n+1}(i,j,k)-E_x^{n-1}(i,j,k)}{2\Delta t} = \frac{1}{\varepsilon}\left\{\left(\frac{H_z^{n+1}(i,j+1,k)-H_z^{n+1}(i,j-1,k)}{2\Delta y}\right)-\left(\frac{H_y^{n+1}(i,j,k+1)-H_y^{n+1}(i,j,k-1)}{2\Delta z}\right)\right\}$$

$$E_x^{n+1}(i,j,k) = E_x^{n-1}(i,j,k)+\frac{\Delta t}{\varepsilon\Delta y}\left(H_z^{n+1}(i,j+1,k)-H_z^{n+1}(i,j-1,k)\right)-\frac{\Delta t}{\varepsilon\Delta z}\left(H_y^{n+1}(i,j,k+1)-H_y^{n+1}(i,j,k-1)\right)$$

Substrate & Stripline Parameters

- Substrate Dimensions ($\varepsilon_r = 2.3$)
  - X – 80 cells
  - Y – 80 cells
  - Z – 4 cells + 10, 20, 30 cells air (varied in steps of 10)
- Stripline on top surface of the substrate
- ABC at extreme boundaries
- Bottom plane coincides with the ground plane
- Feed point (transmitting port) at one end of the stripline, coinciding with ABC
- Receiving port at the other end, coinciding with ABC

Surface Plot - Two Port Transmission Line



Voltage Calculation

- Voltage calculated by integrating E along a single line 5 cells into the substrate
  - Initially, voltage was averaged over all such lines lying within the strip width
  - For plotting, the voltage was calculated only along the central line while the entire source was illuminated
- Integral approximated by a summation along y-direction (4 cells high)

```
transmit_Voltage(count) = (sum(ey(feed_x,strip_y1:strip_y2,feed_z1+5)))*dy;
receive_Voltage(count) = (sum(ey(feed_x,strip_y1:strip_y2,feed_z2-5)))*dy;
```

Current Calculation

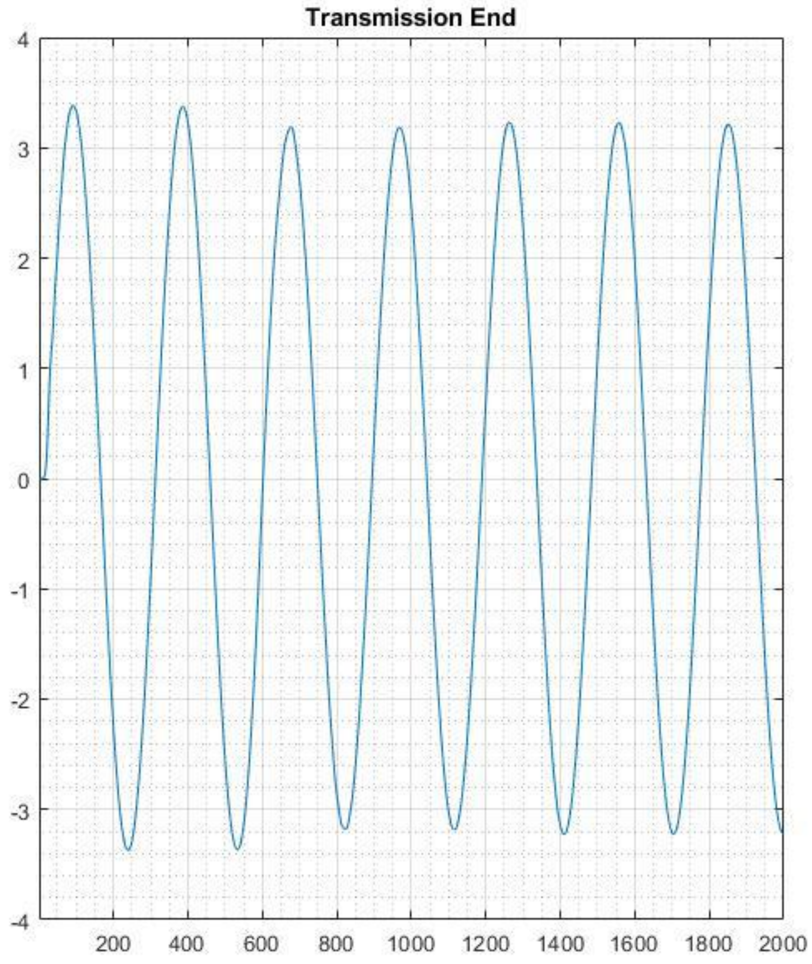
- Current calculated by using Ampere's loop law 5 cells into the substrate

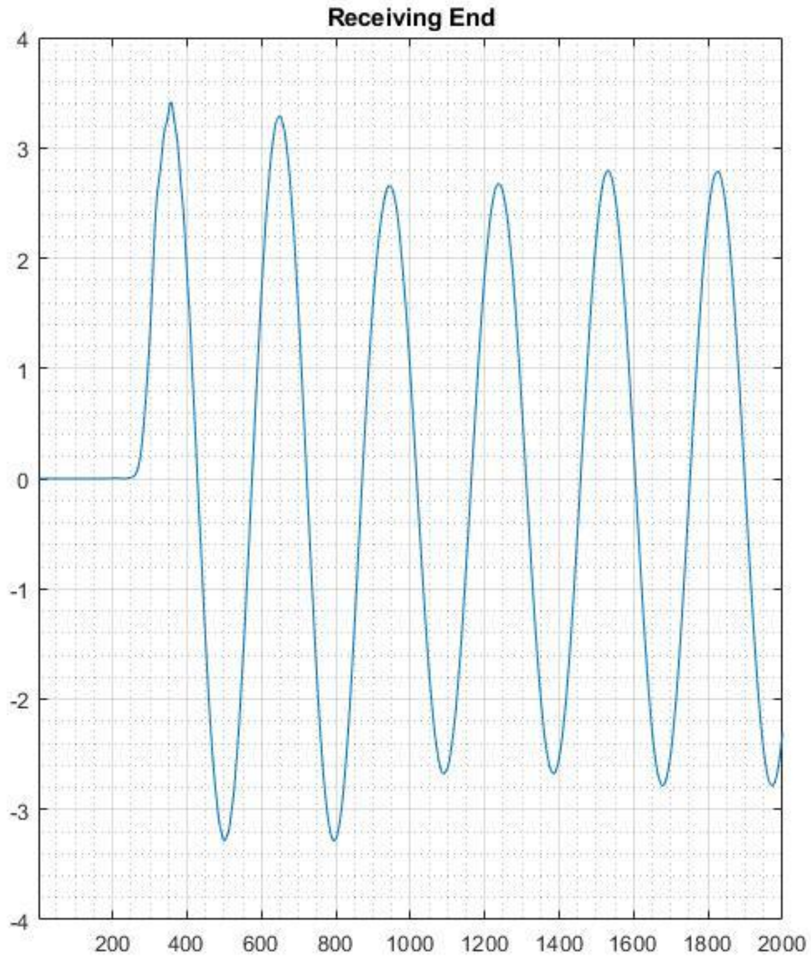
$$I_s^{n-1/2} = (H_x^{n-1/2}(i_s, j_s - 1, k_s) - H_x^{n-1/2}(i_s, j_s, k_s))\Delta x \\ + (H_y^{n-1/2}(i_s, j_s, k_s) - H_y^{n-1/2}(i_s - 1, j_s, k_s))\Delta y$$

- Above equation only valid for right handed coordinate systems
- For our case, a – ve sign should appear at the beginning

```
transmit_Current(count) = -((hx(feed_x,y_mid,feed_z1+5)-hx(feed_x,y_mid,feed_z1+6))*dx + (hz(feed_x,y_mid,feed_z1+6)-hz(feed_x-1,y_mid,feed_z1+6))*dz);
receive_Current(count)  = -((hx(feed_x,y_mid,feed_z2-6)-hx(feed_x,y_mid,feed_z2-5))*dx + (hz(feed_x,y_mid,feed_z2-5)-hz(feed_x-1,y_mid,feed_z2-5))*dz);
```

Sinusoidal Pulse (v = 5 GHz) [Air column height = 30 cells]





Voltage

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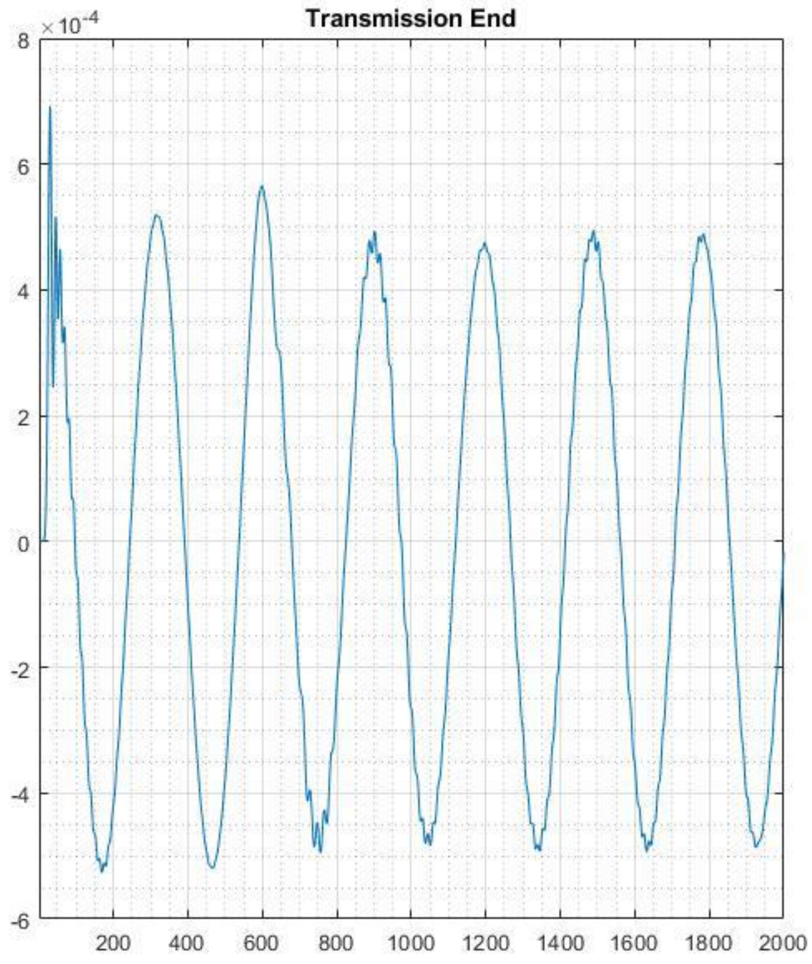

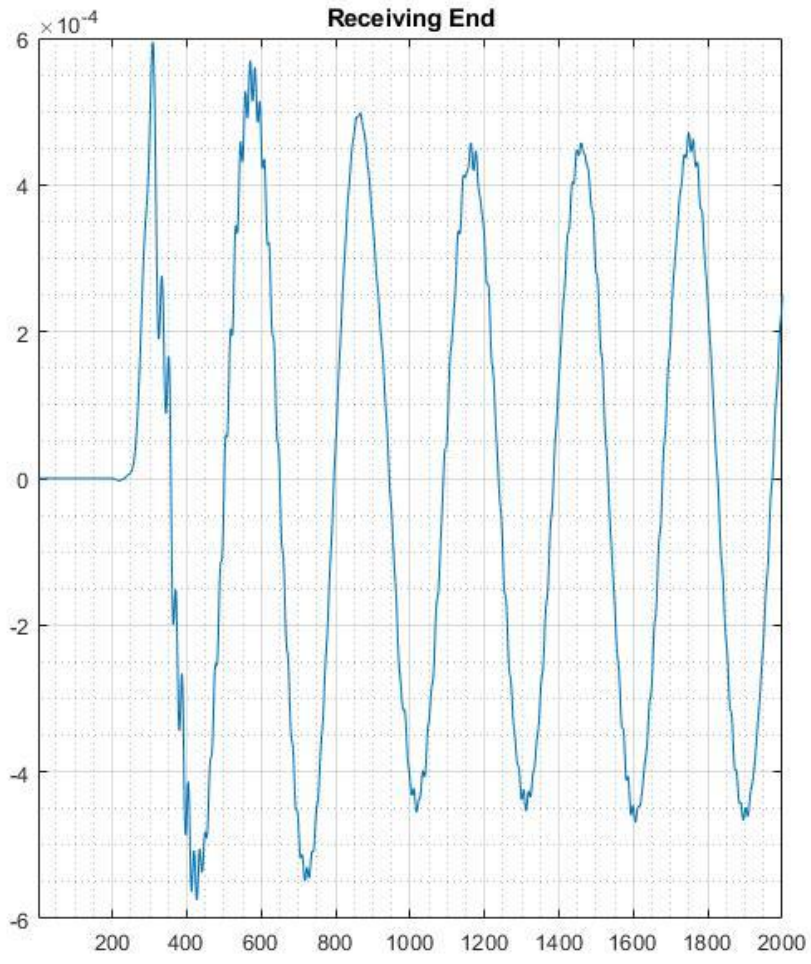

Current

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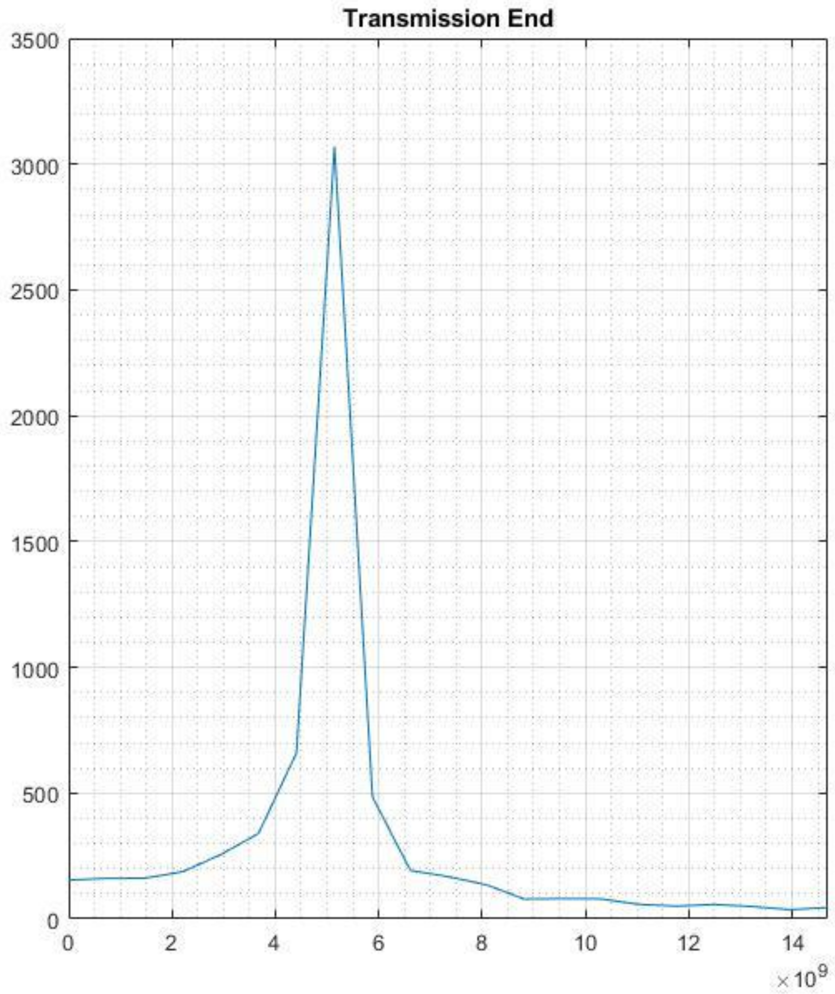

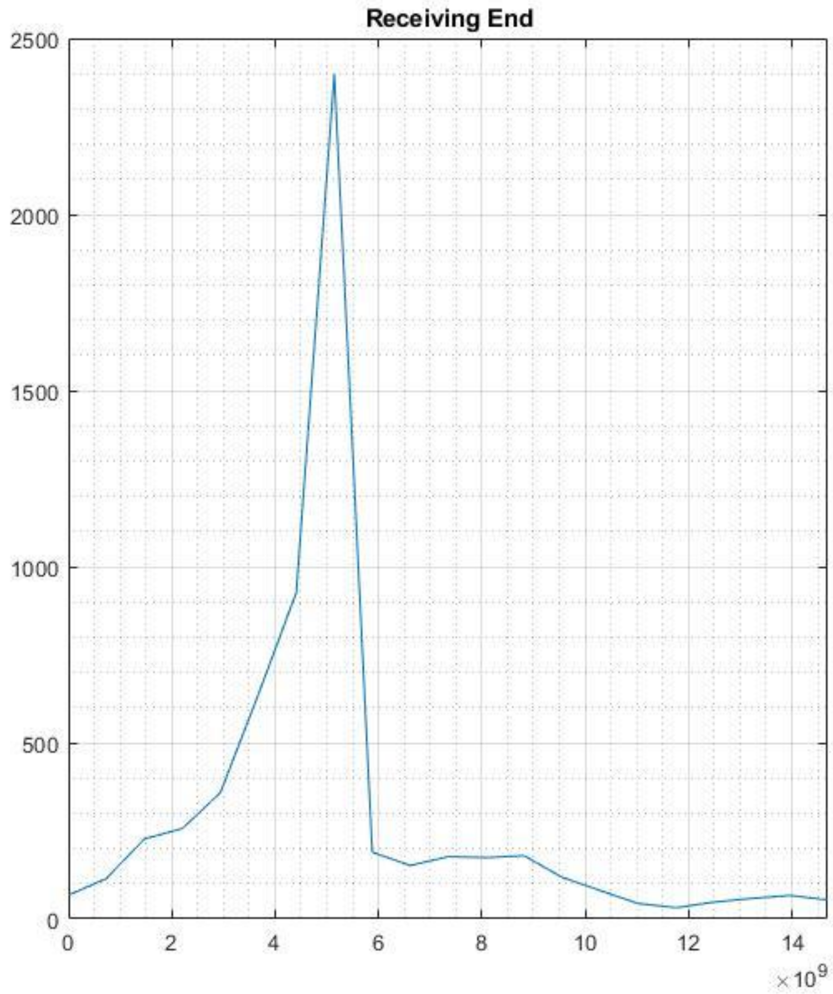

Voltage FFT

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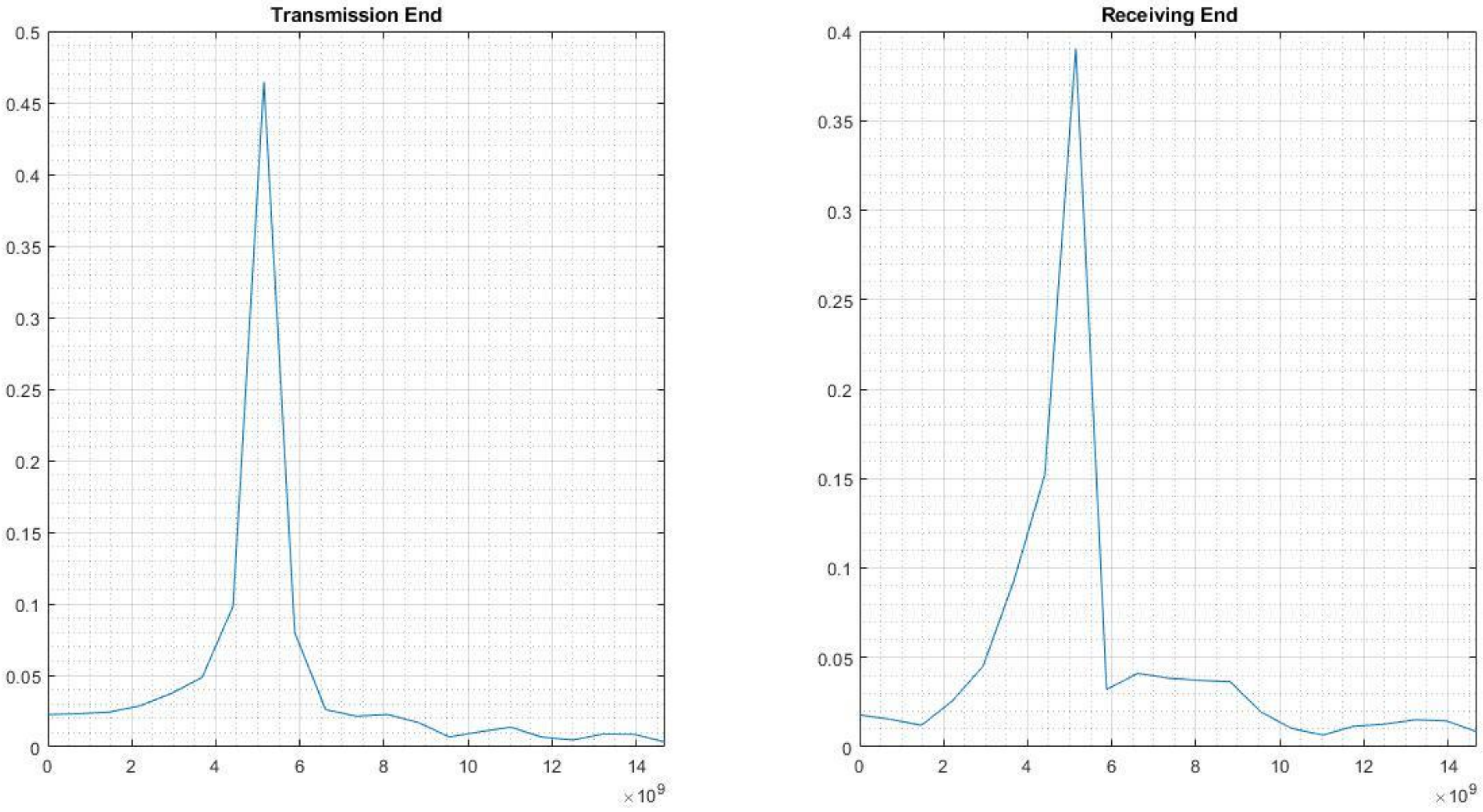
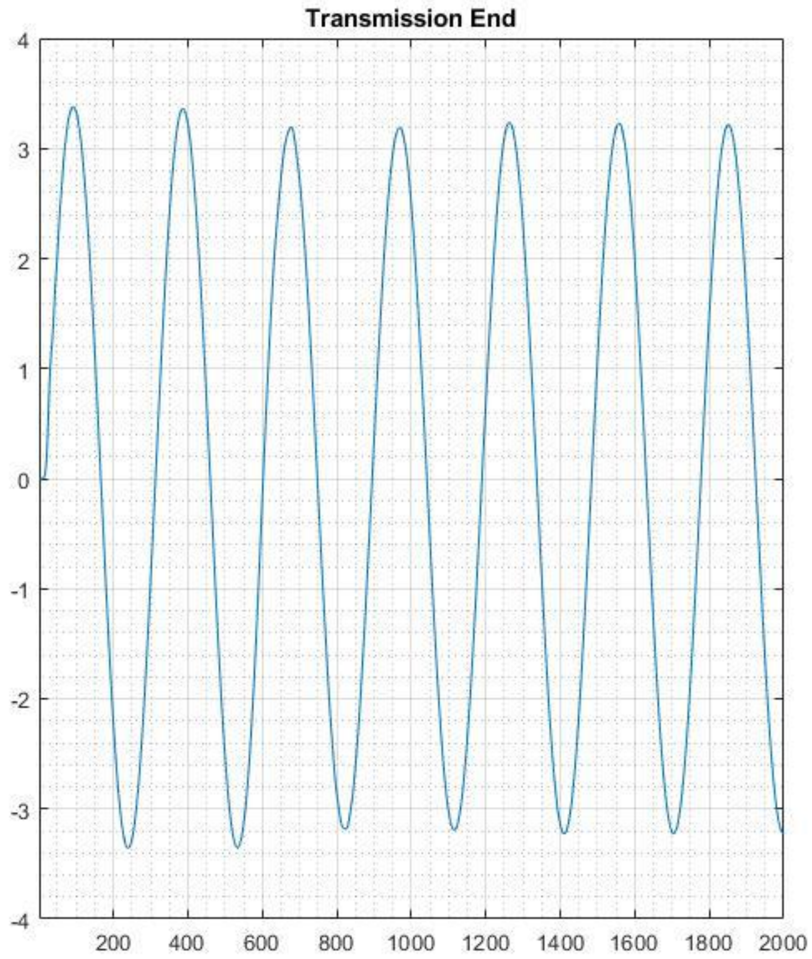
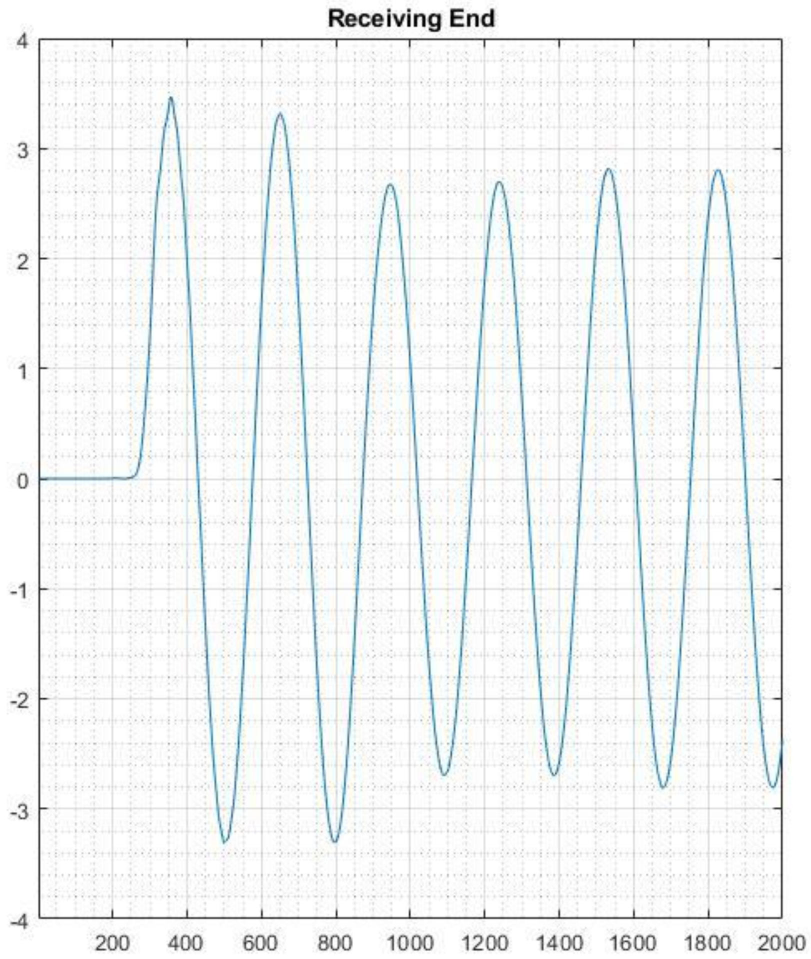


Current FFT

Sinusoidal Pulse (v = 5 GHz) [Air column height = 20 cells]





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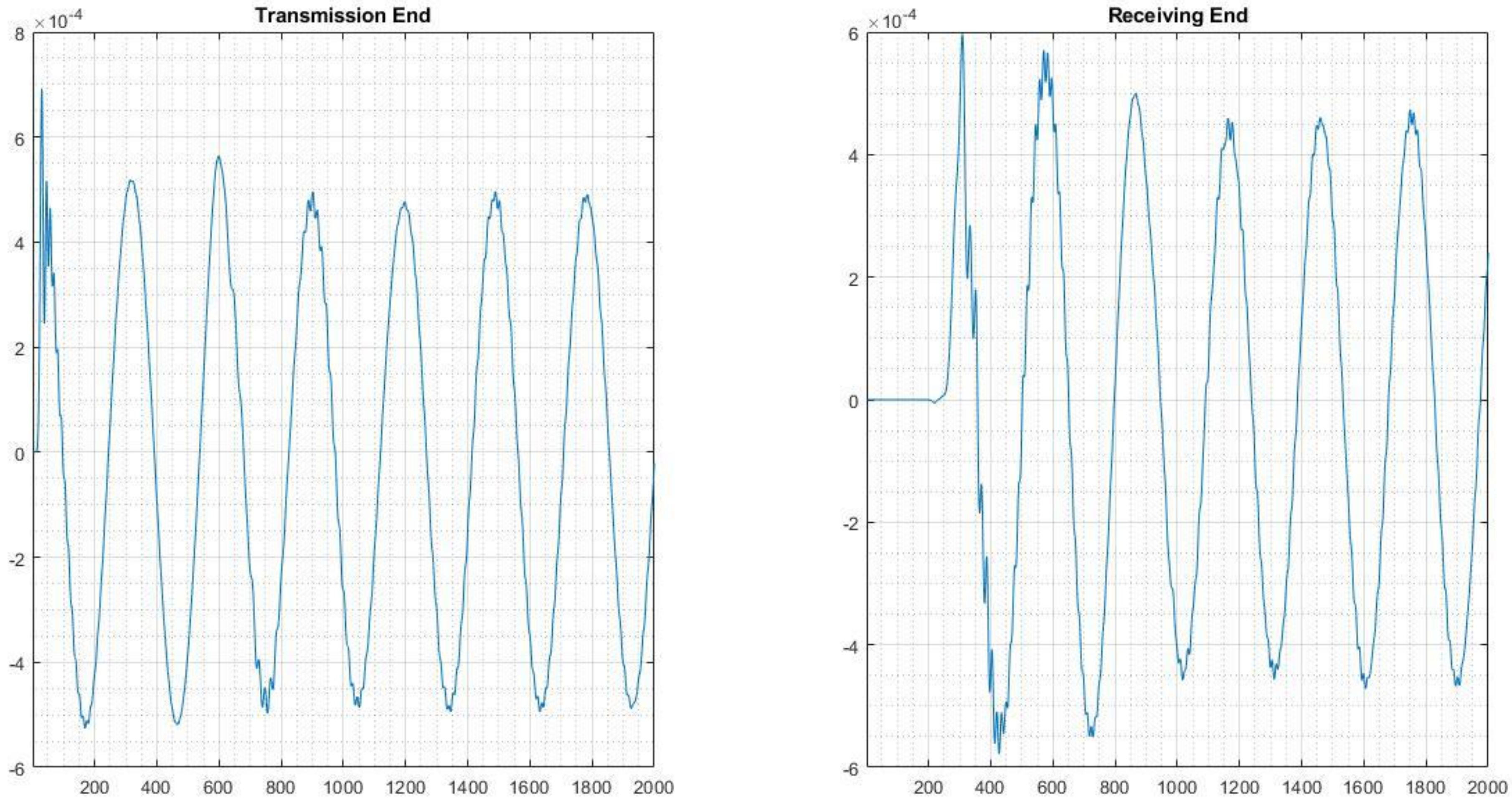

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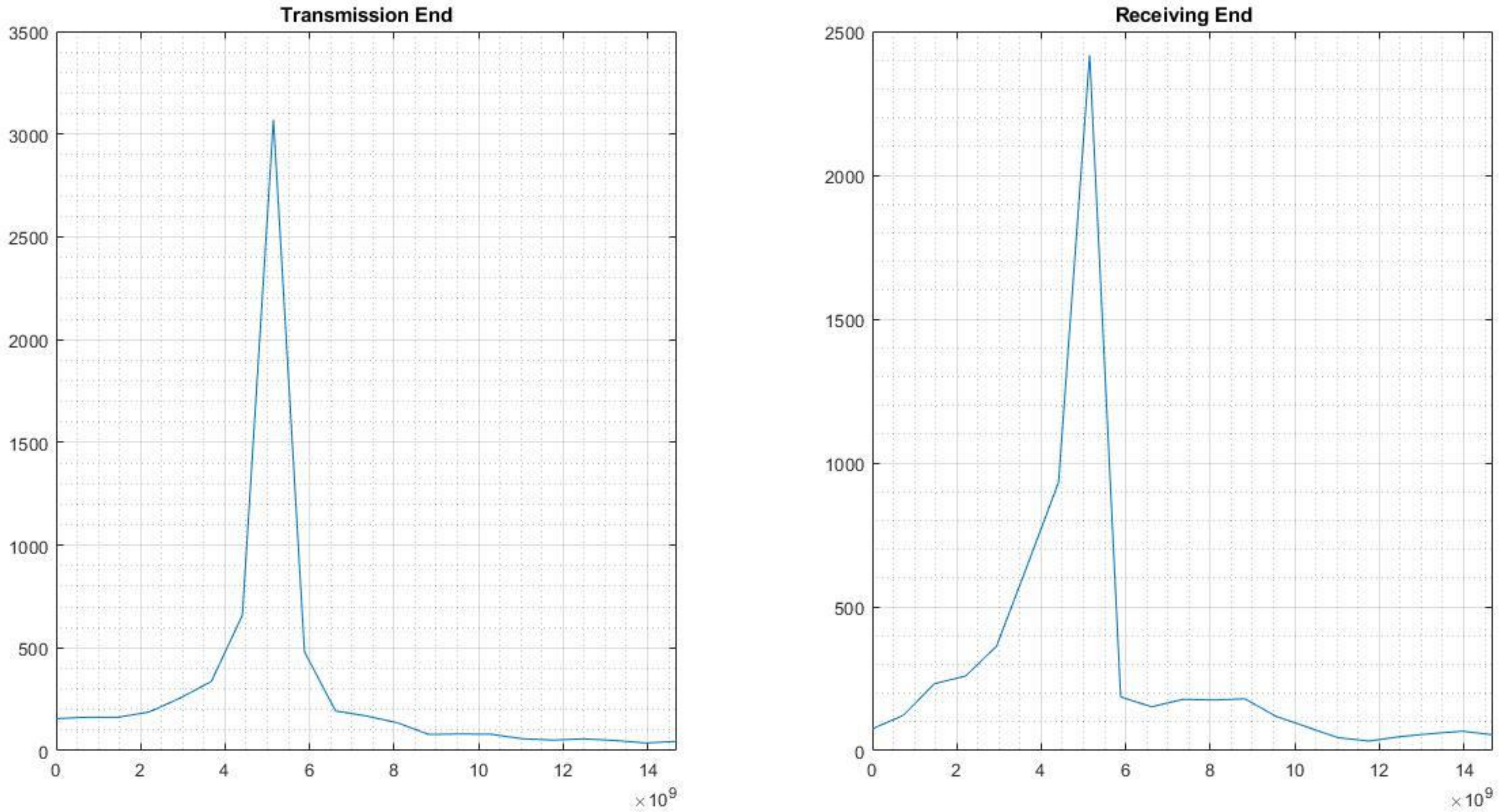

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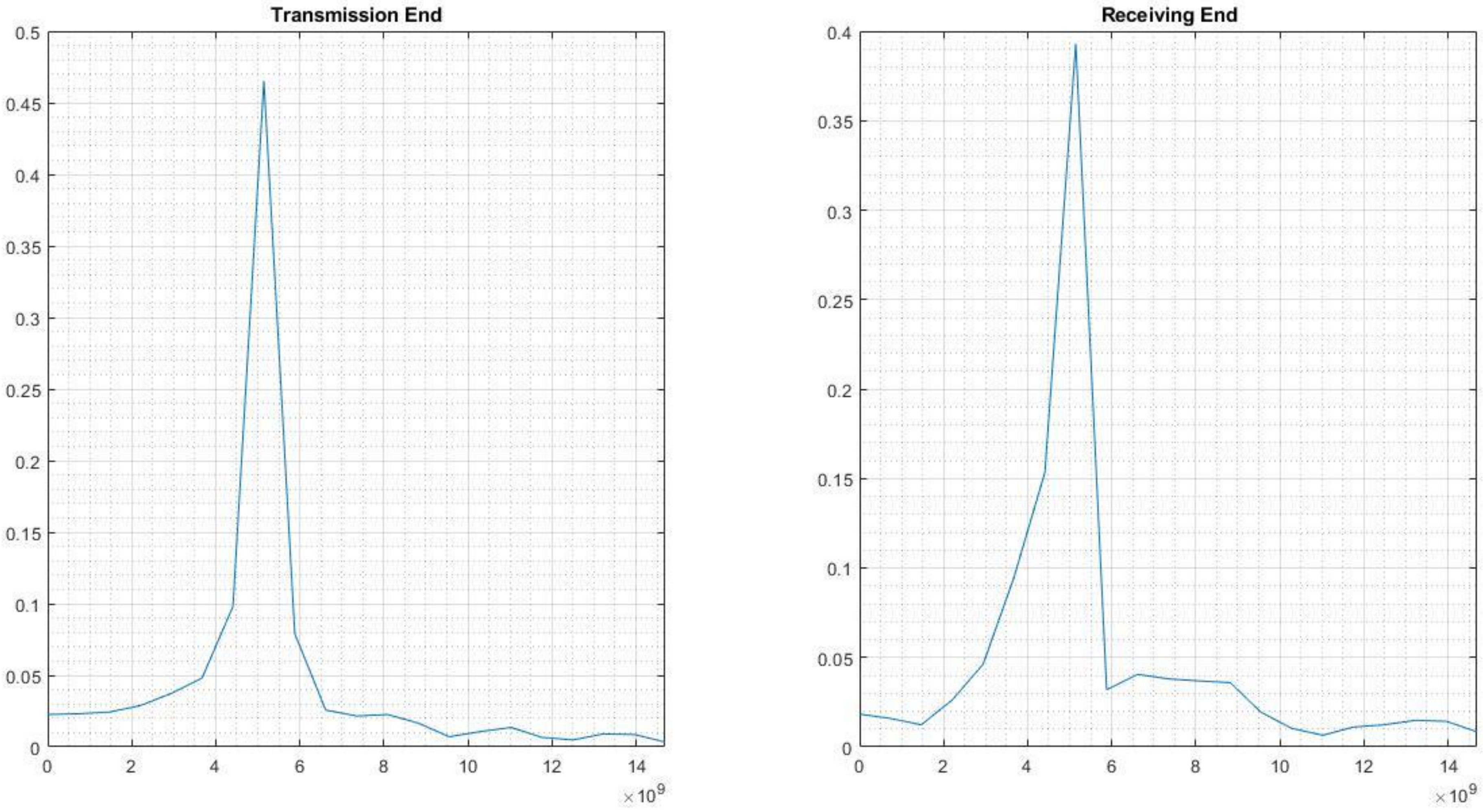
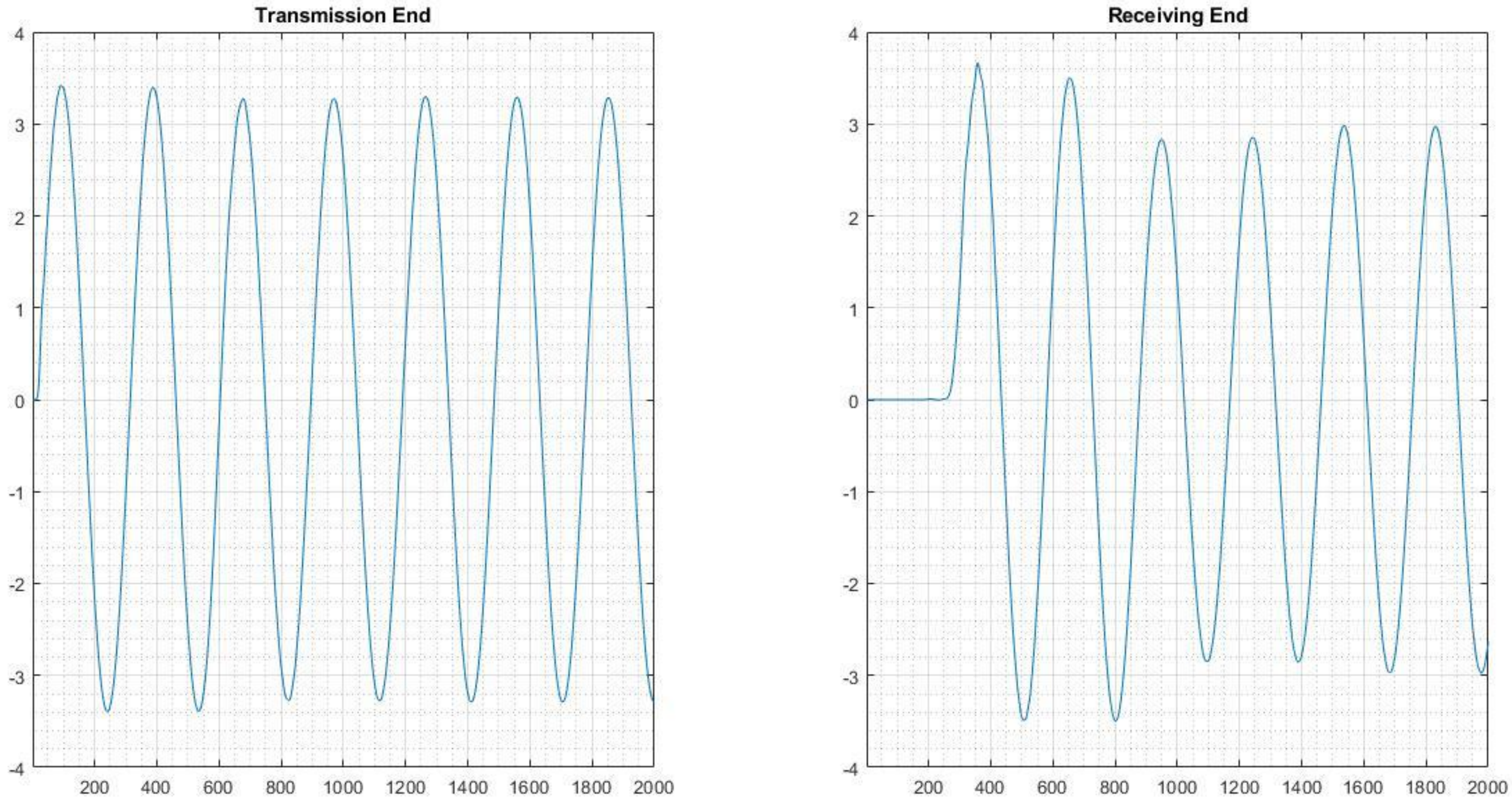


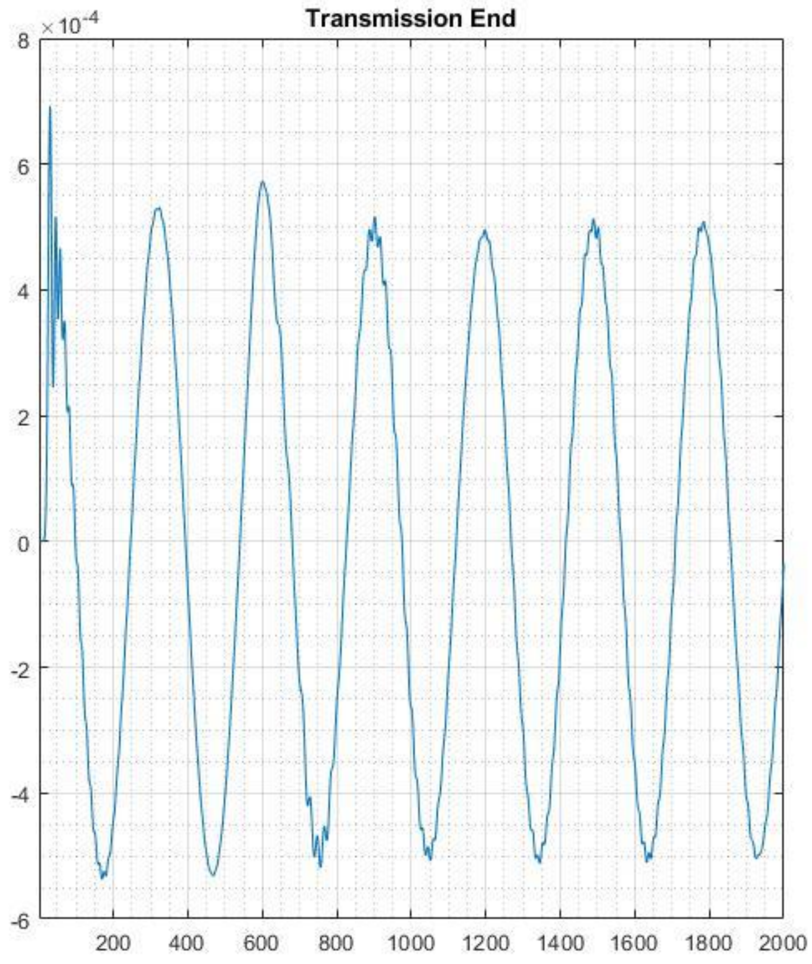
Current FFT

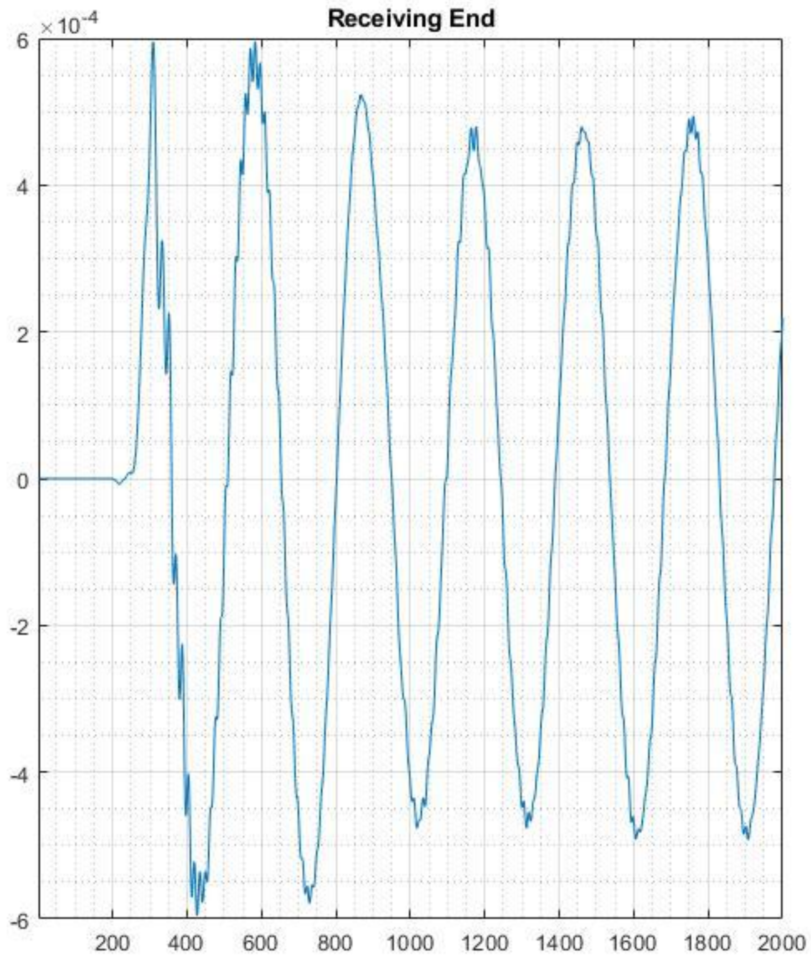
Sinusoidal Pulse (v = 5 GHz) [Air column height = 10 cells]



Voltage

Sinusoidal Pulse (ν = 5 GHz) [Air column height = 10 cells]





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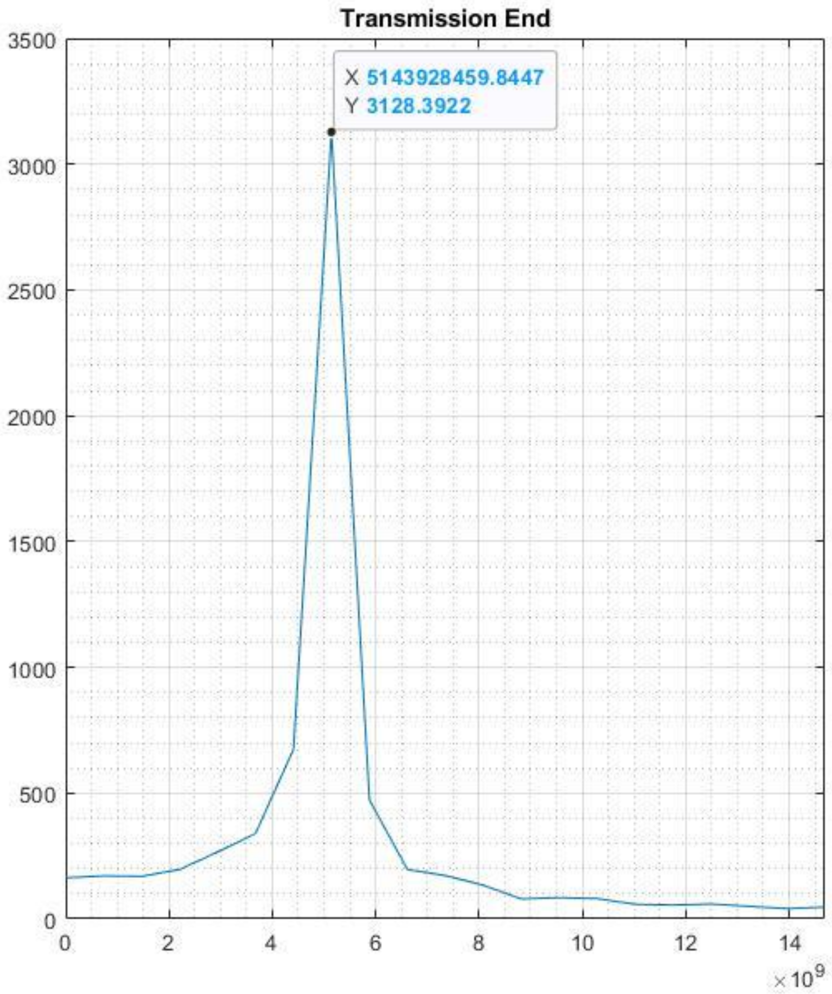

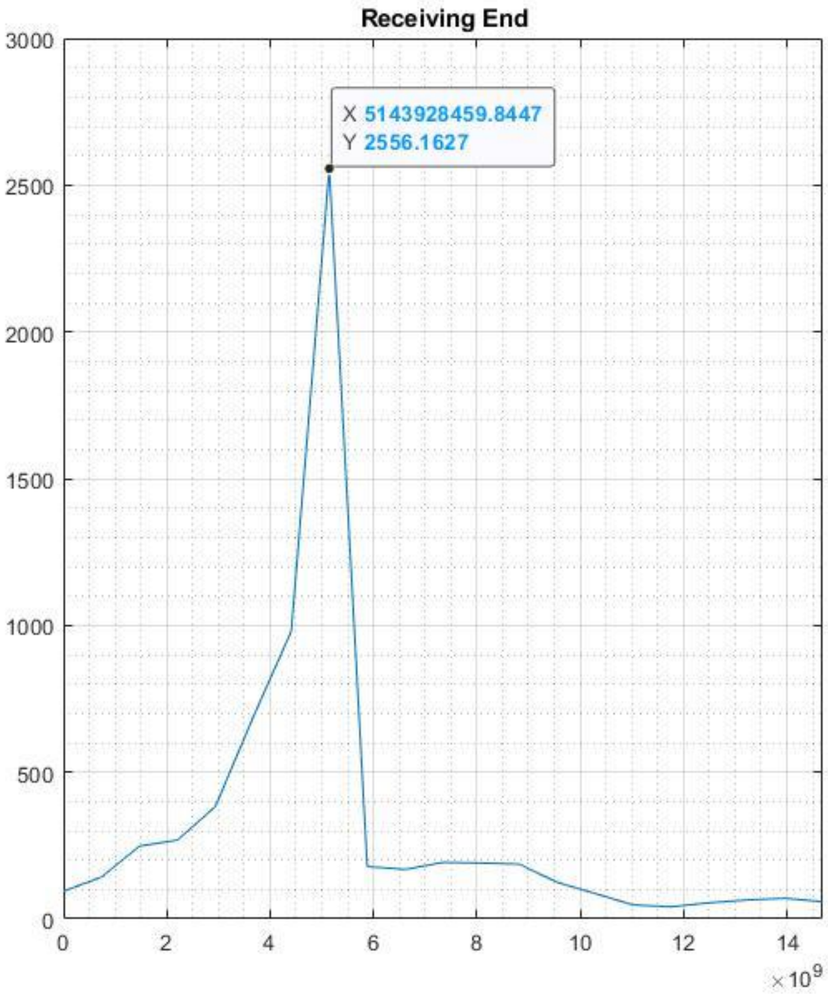

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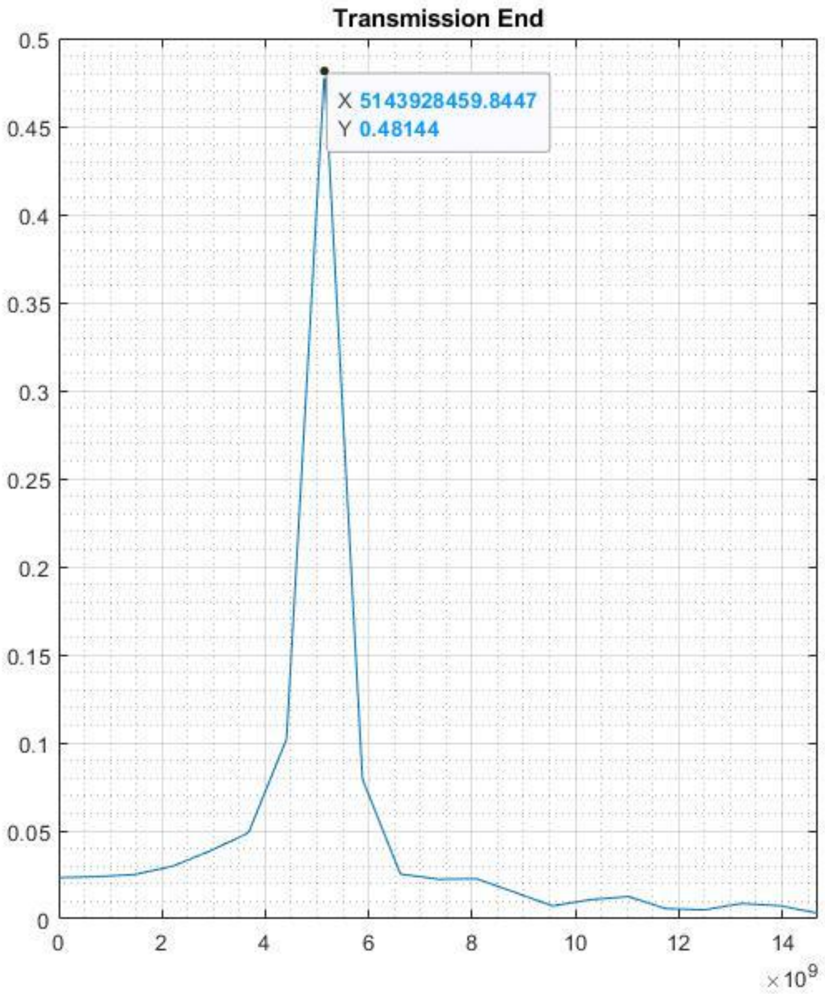
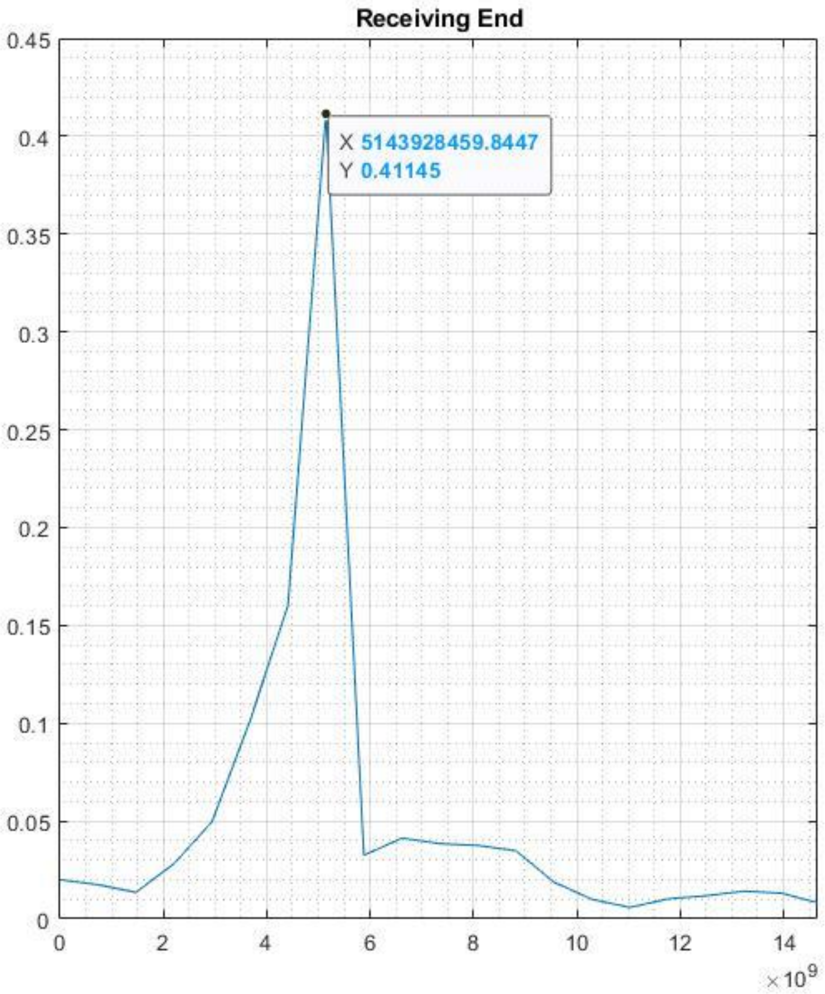
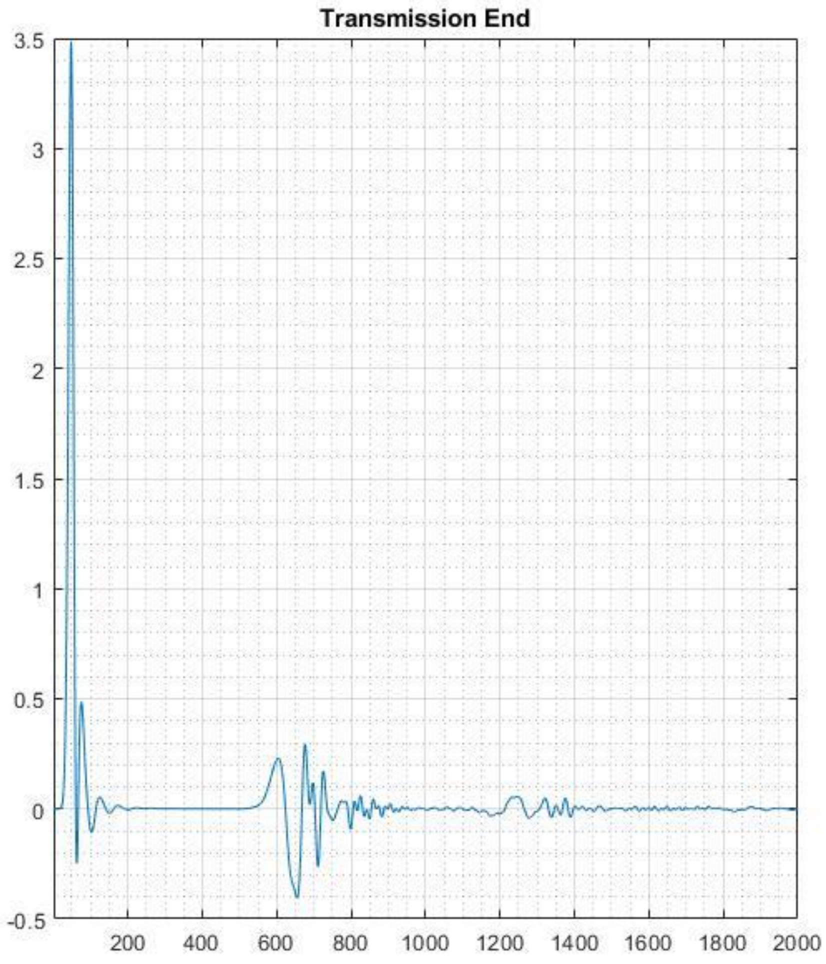
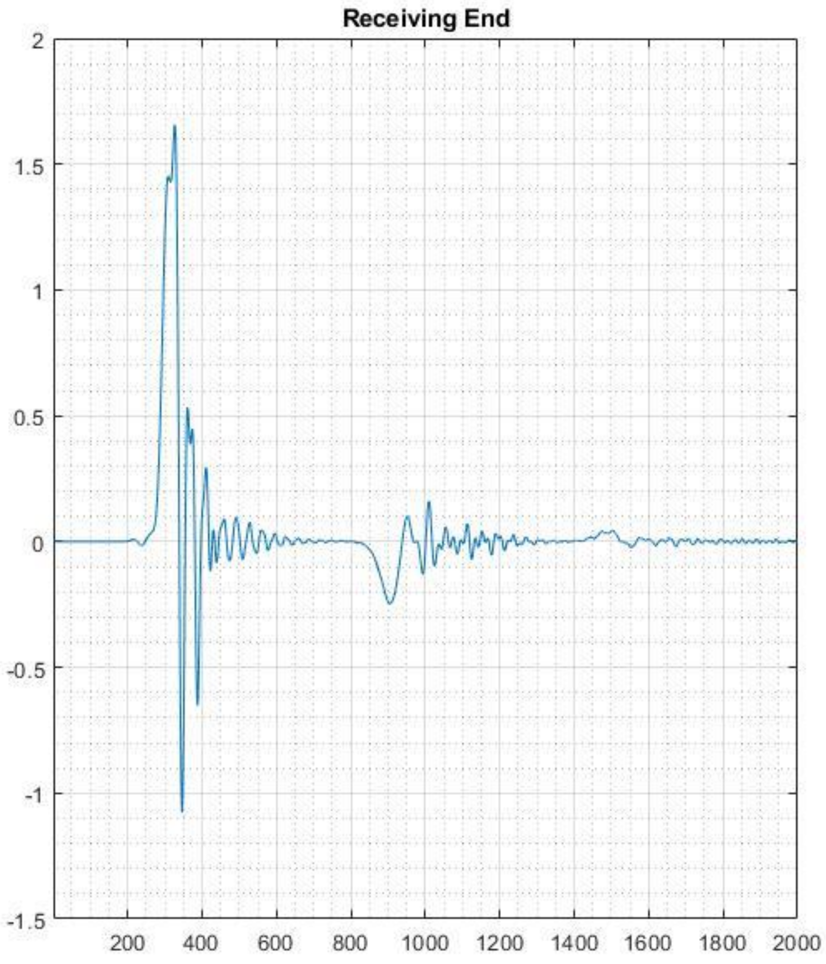




Current FFT

Gaussian Pulse [Air column height = 30 cells]





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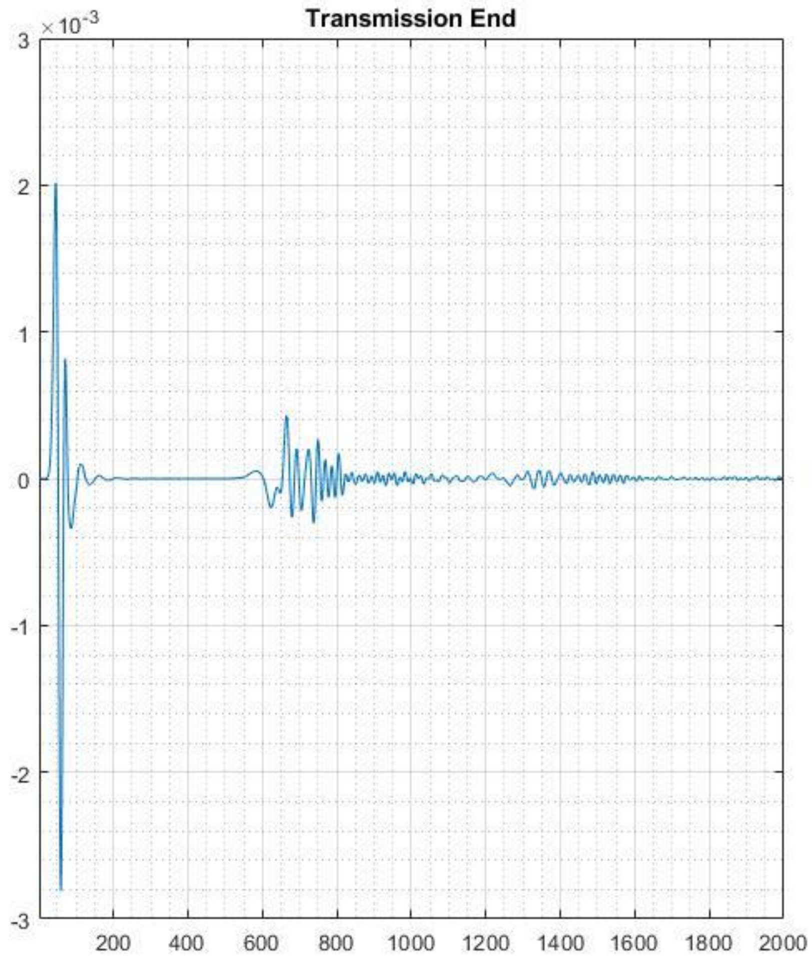

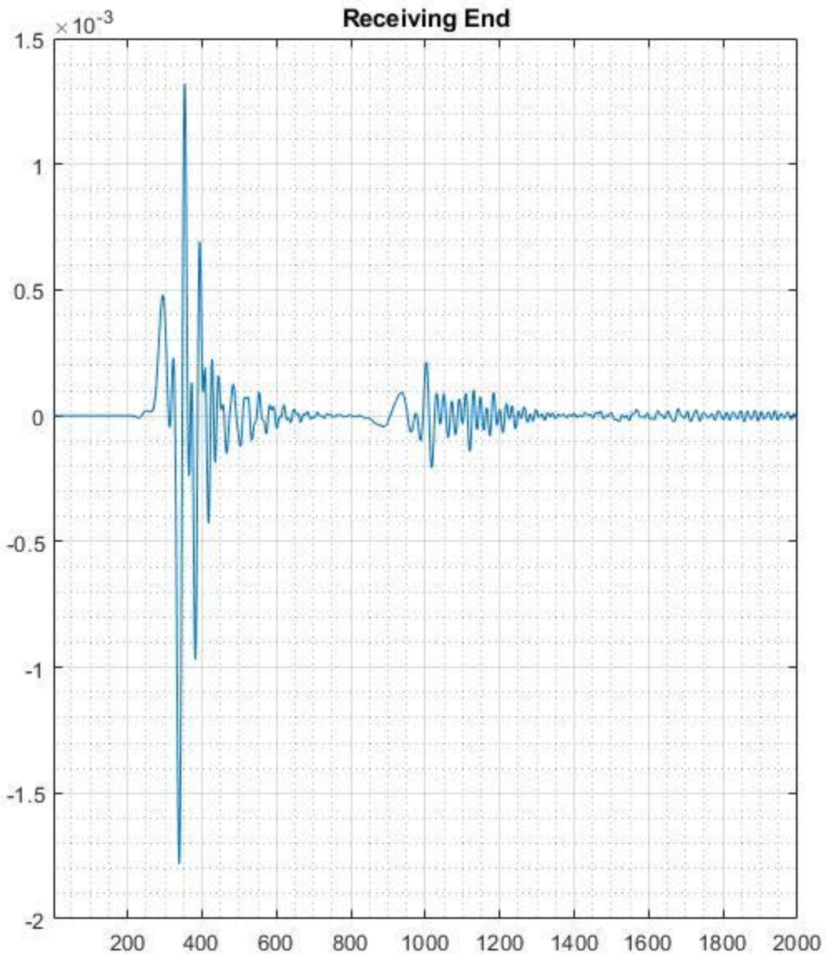

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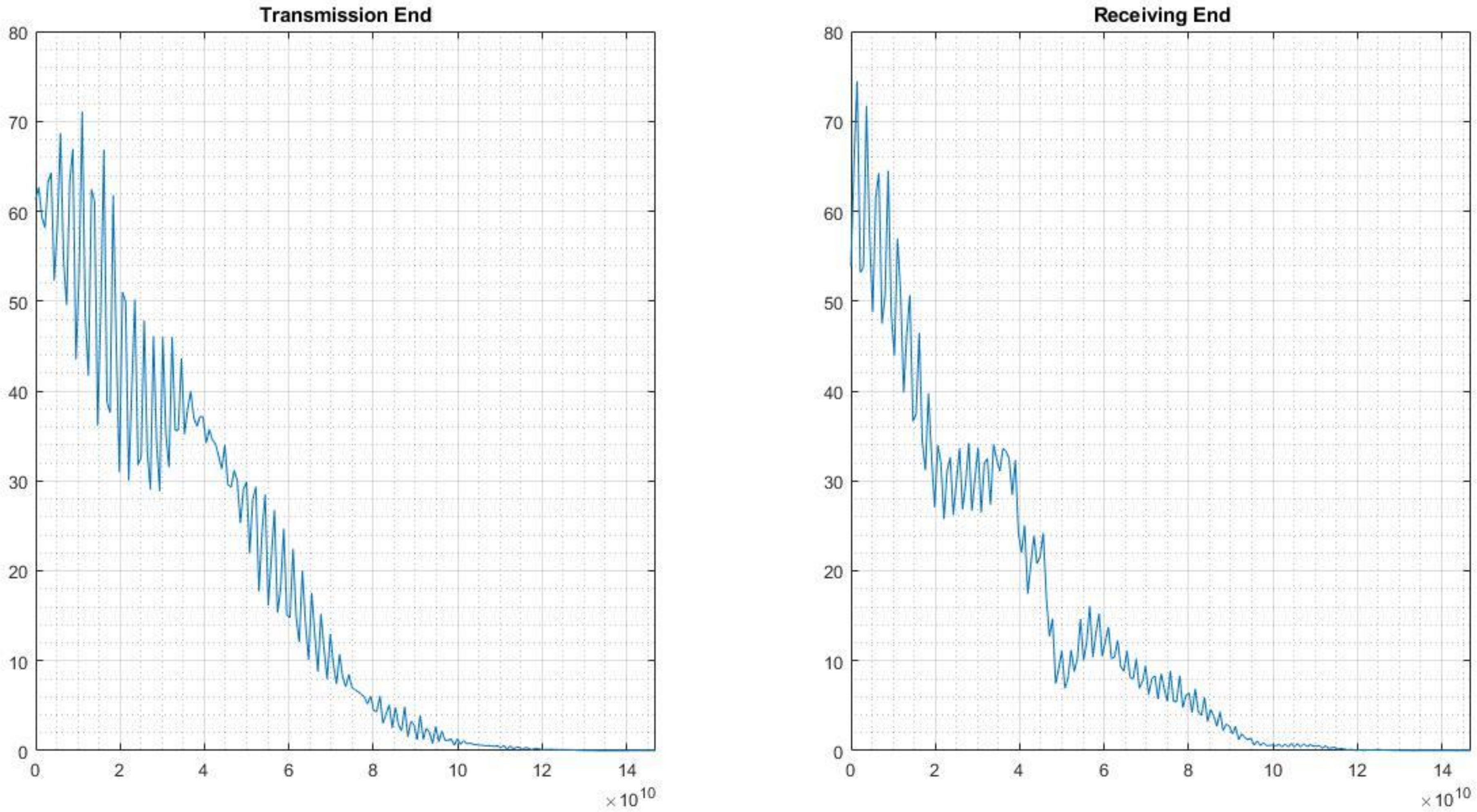

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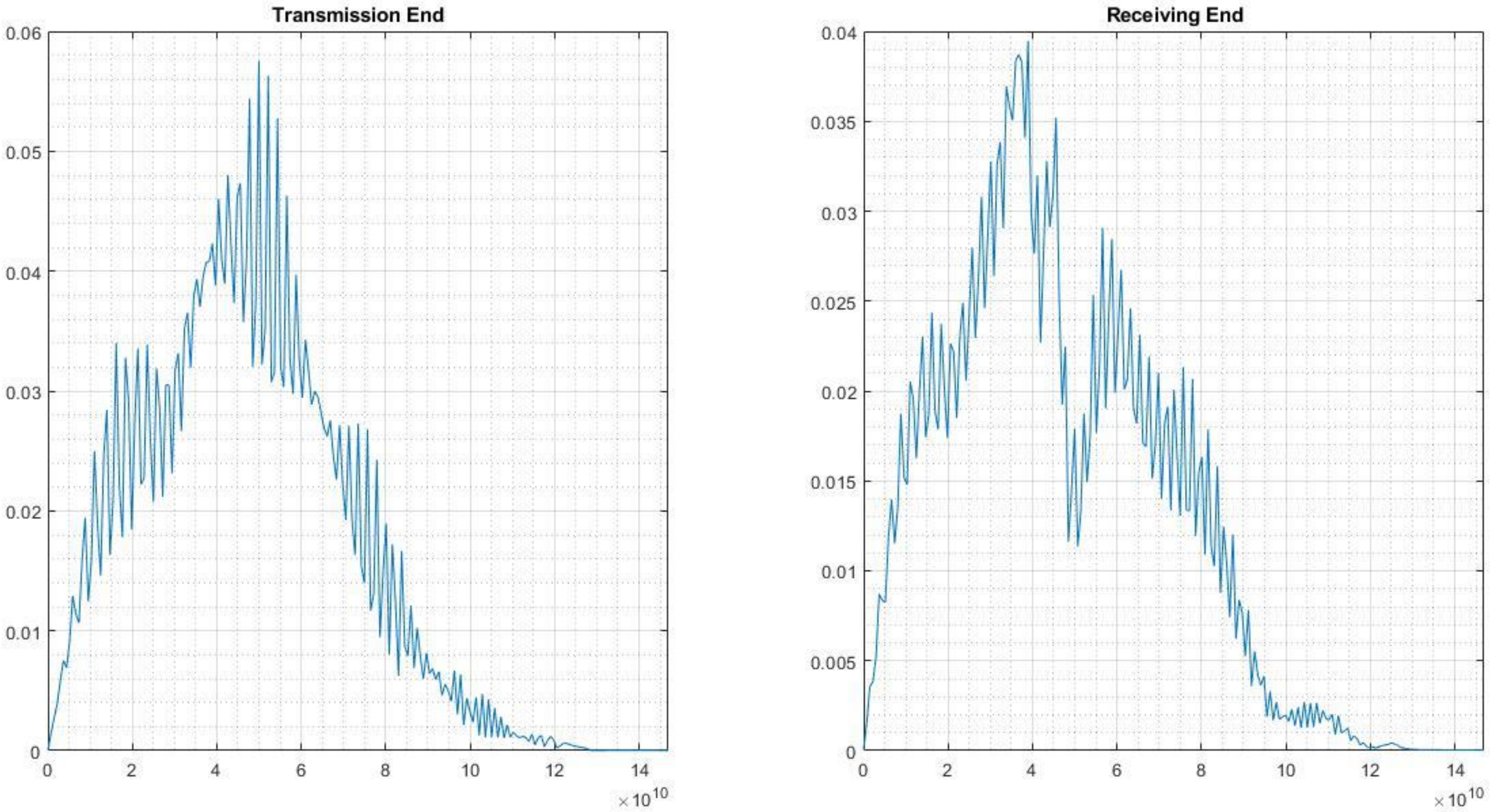
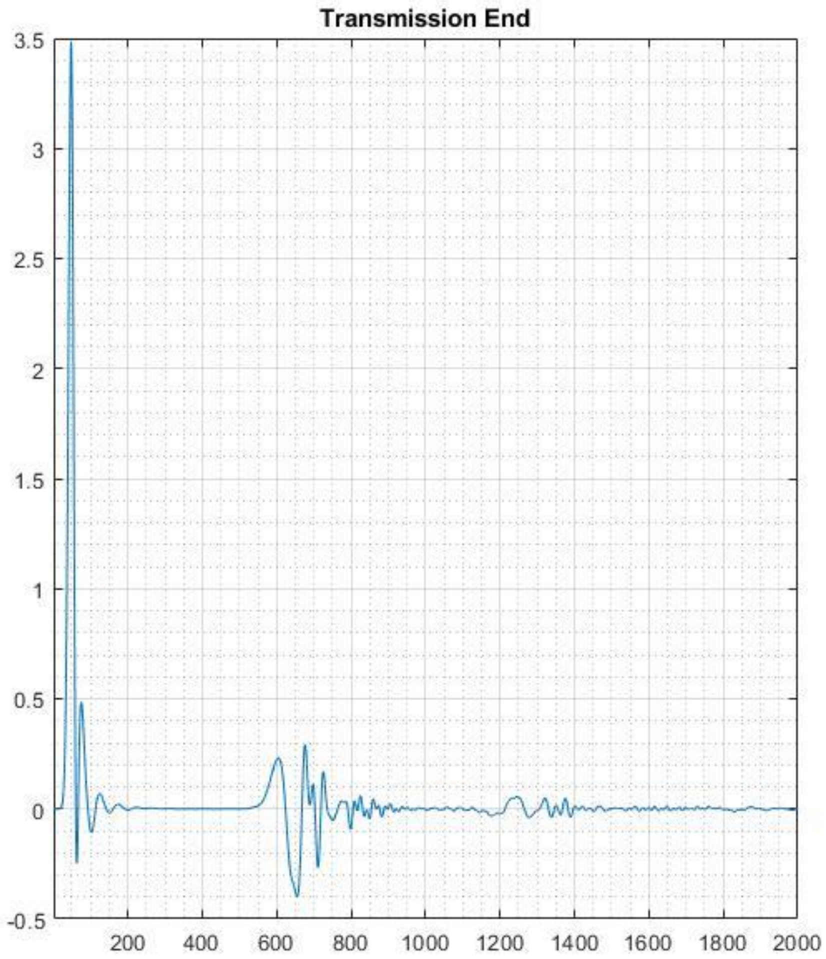
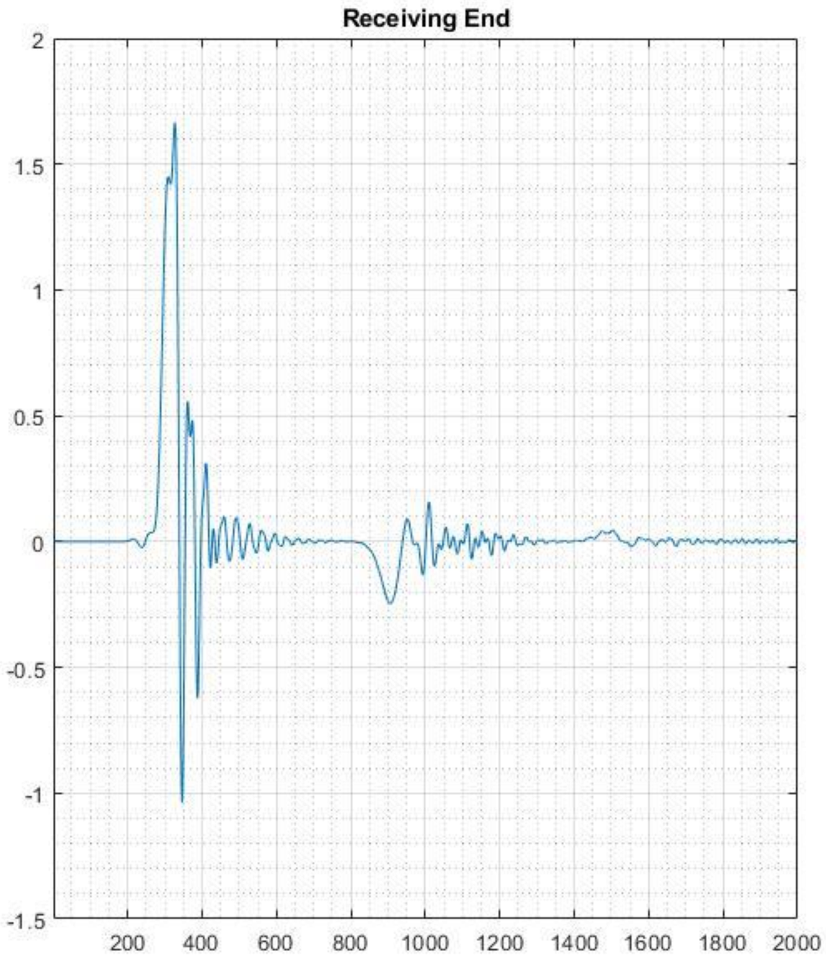


Current FFT

Gaussian Pulse [Air column height = 20 cells]





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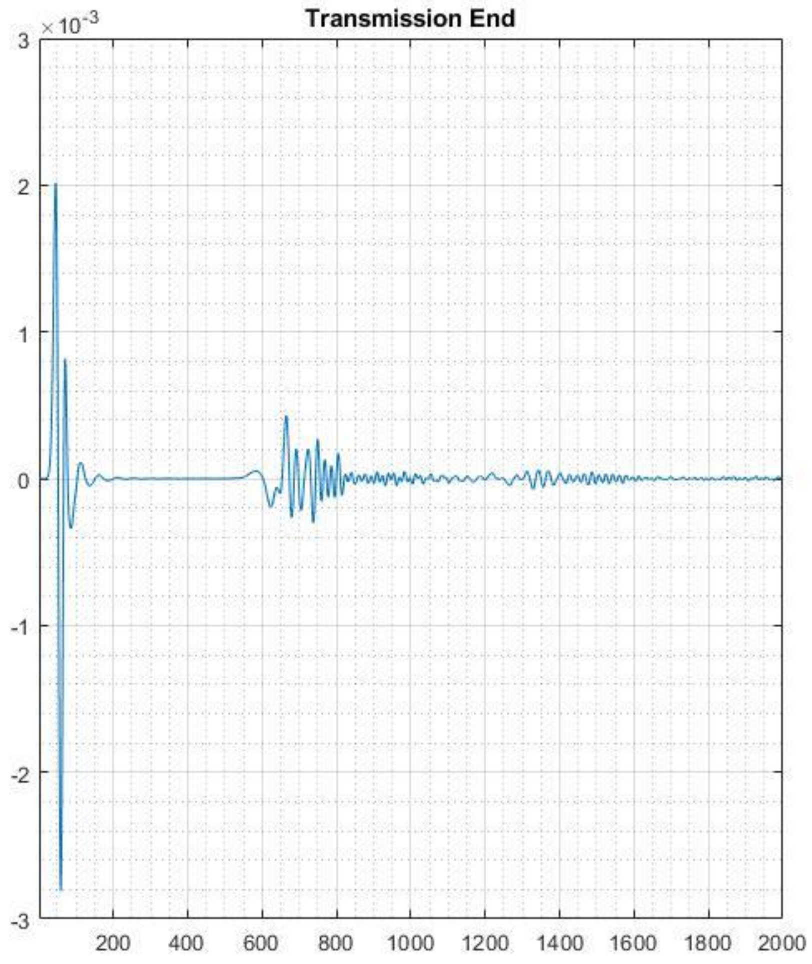

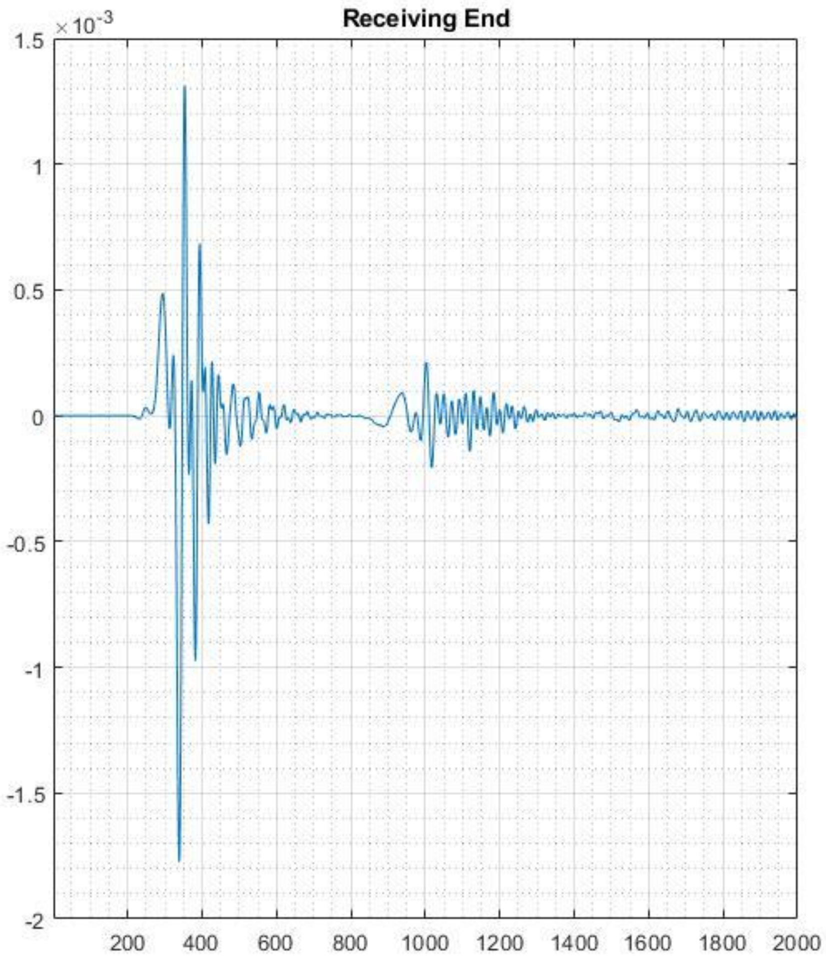

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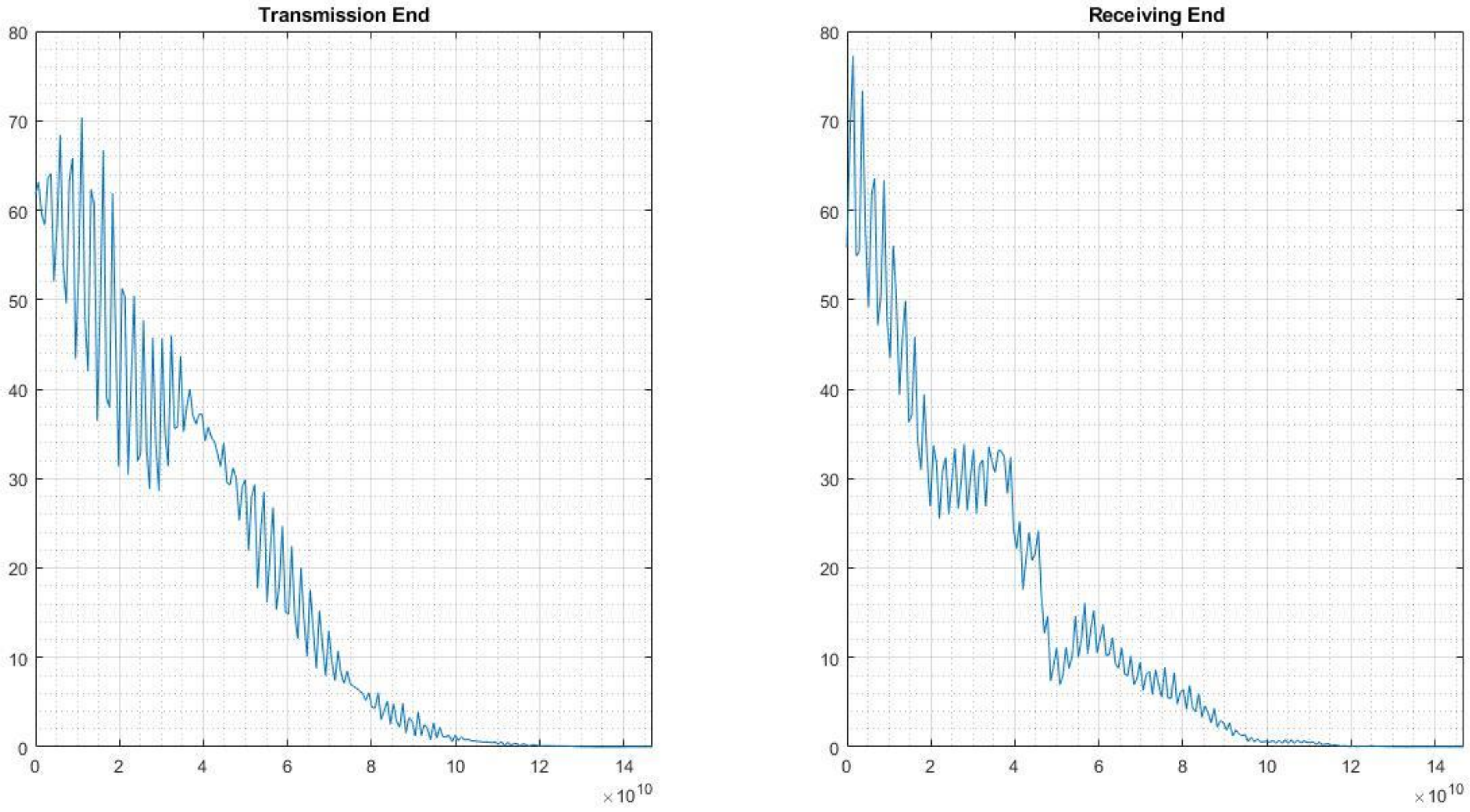

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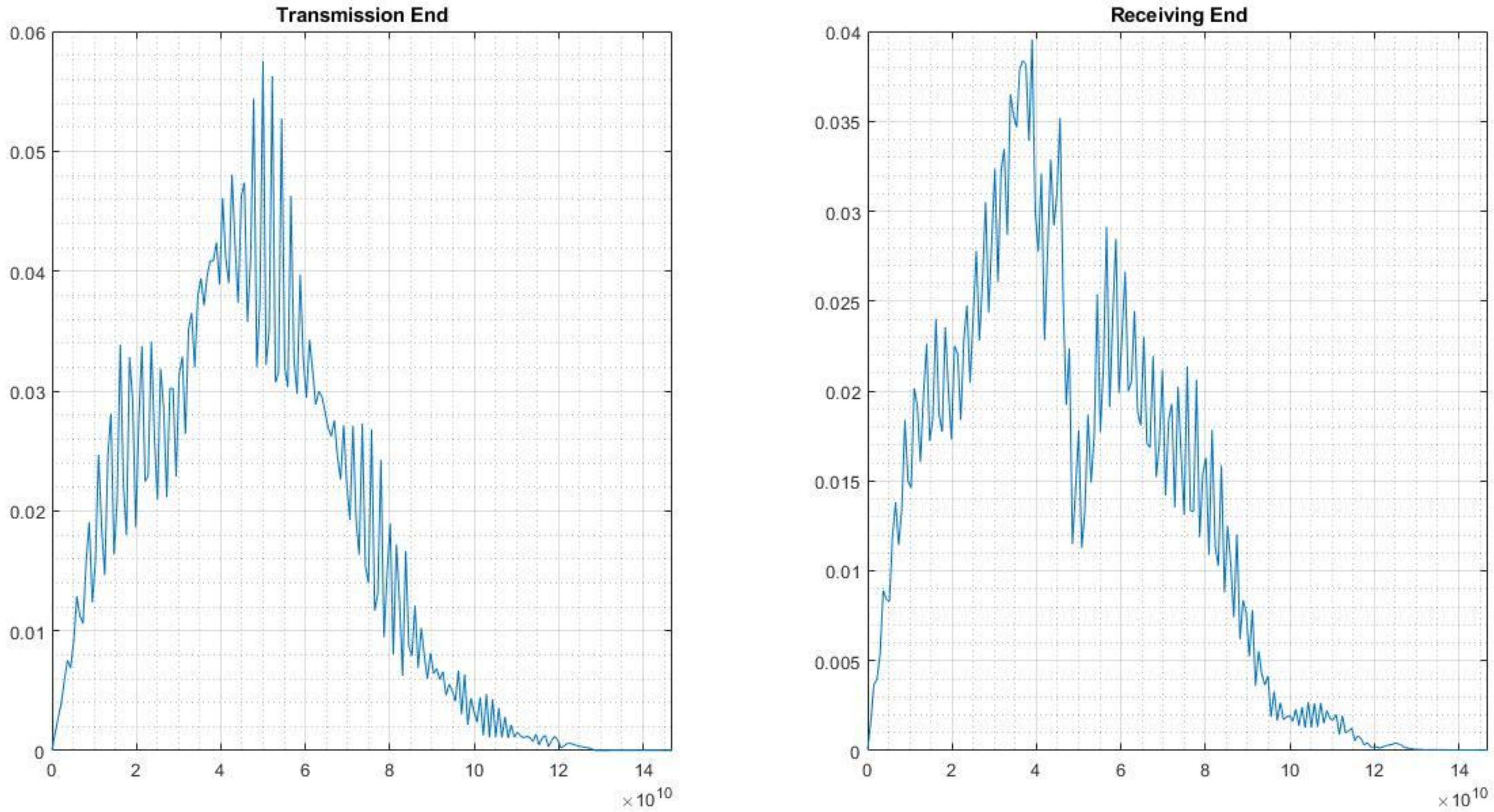
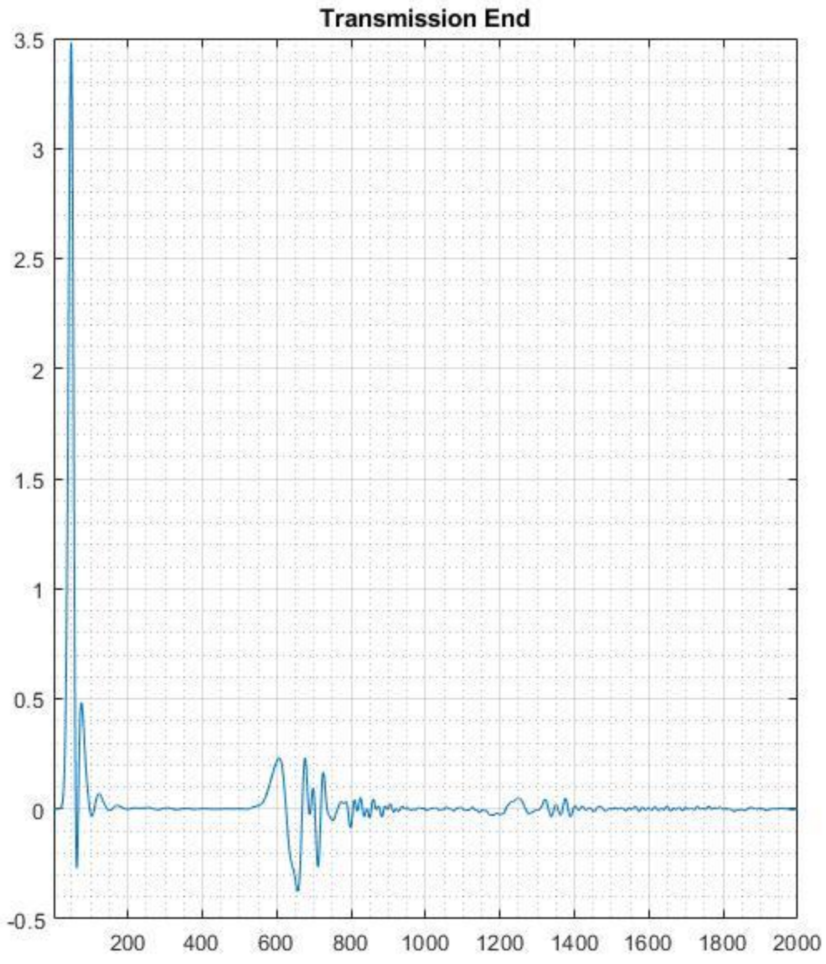
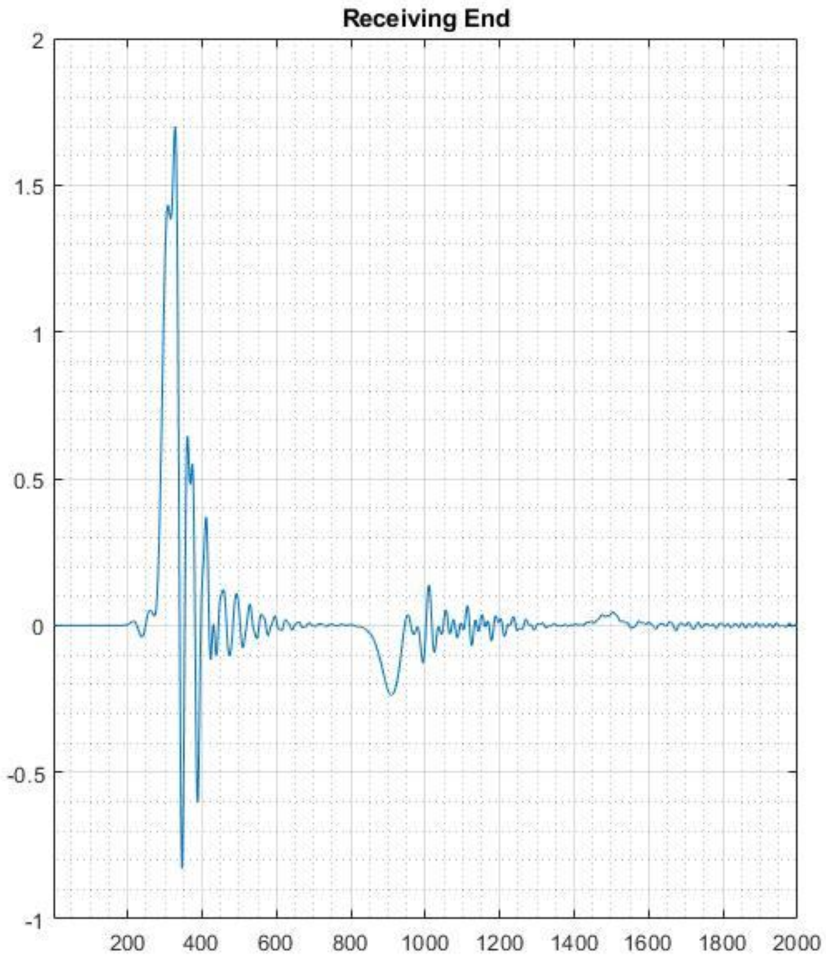


Current FFT

Gaussian Pulse [Air column height = 10 cells]





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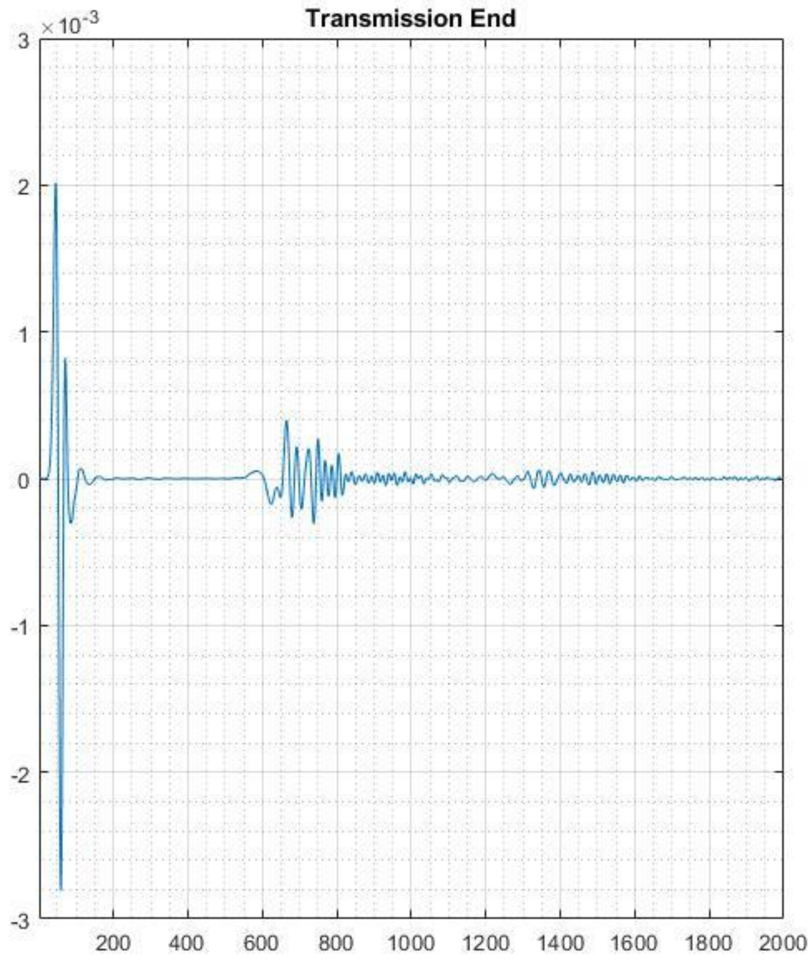

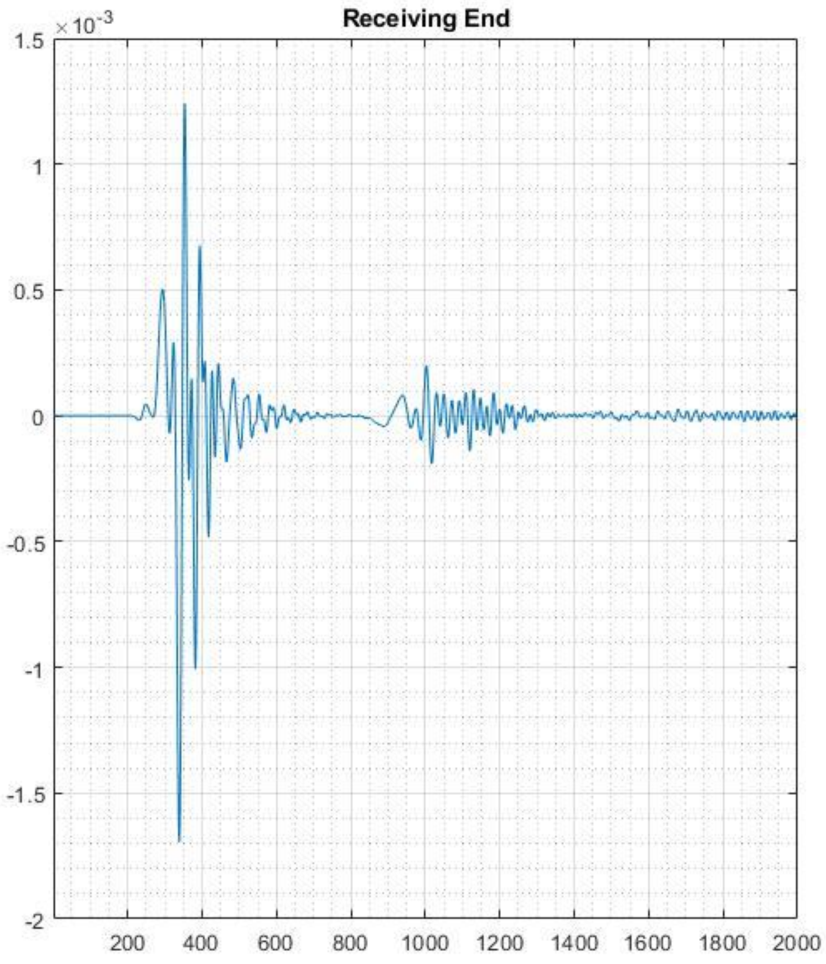

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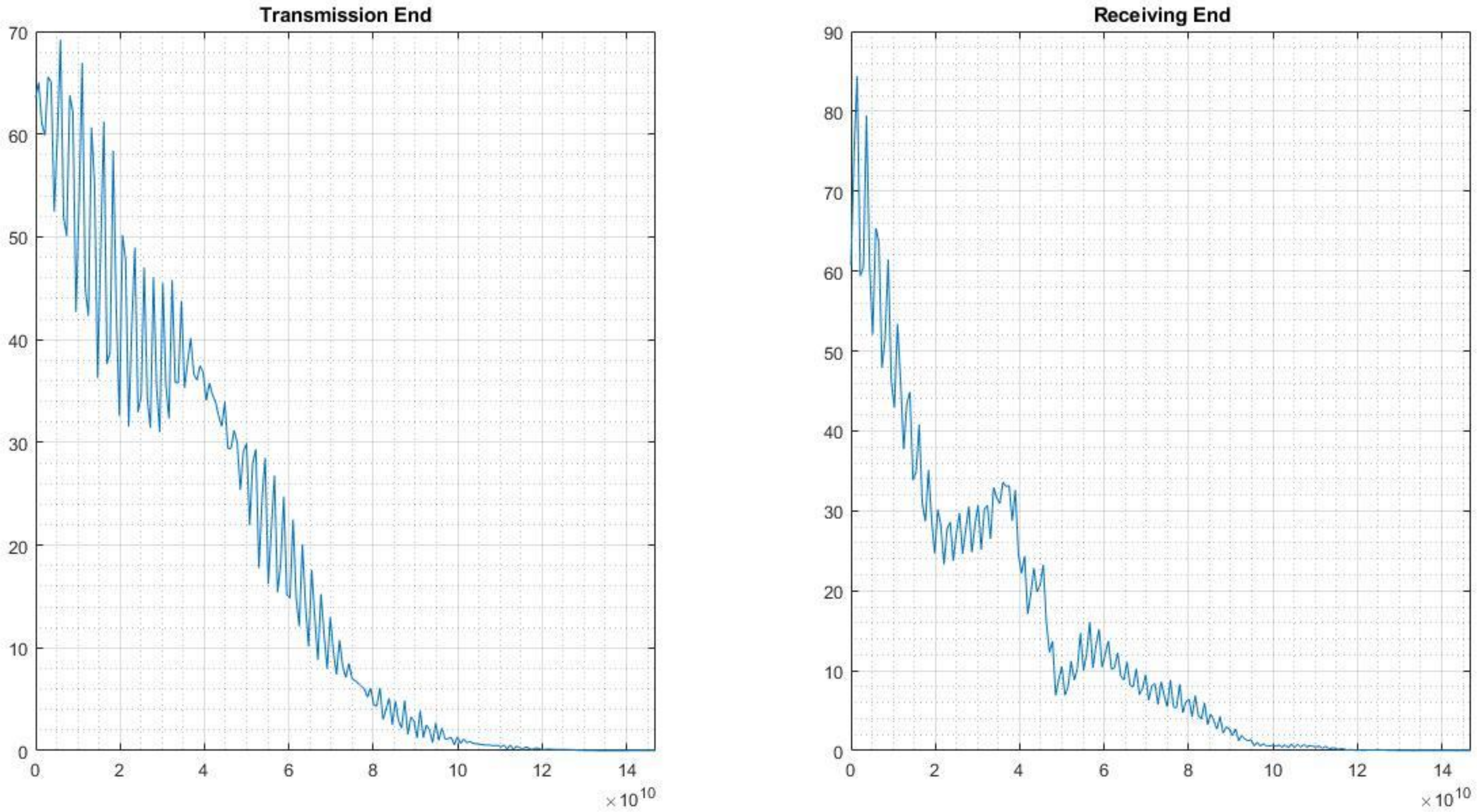

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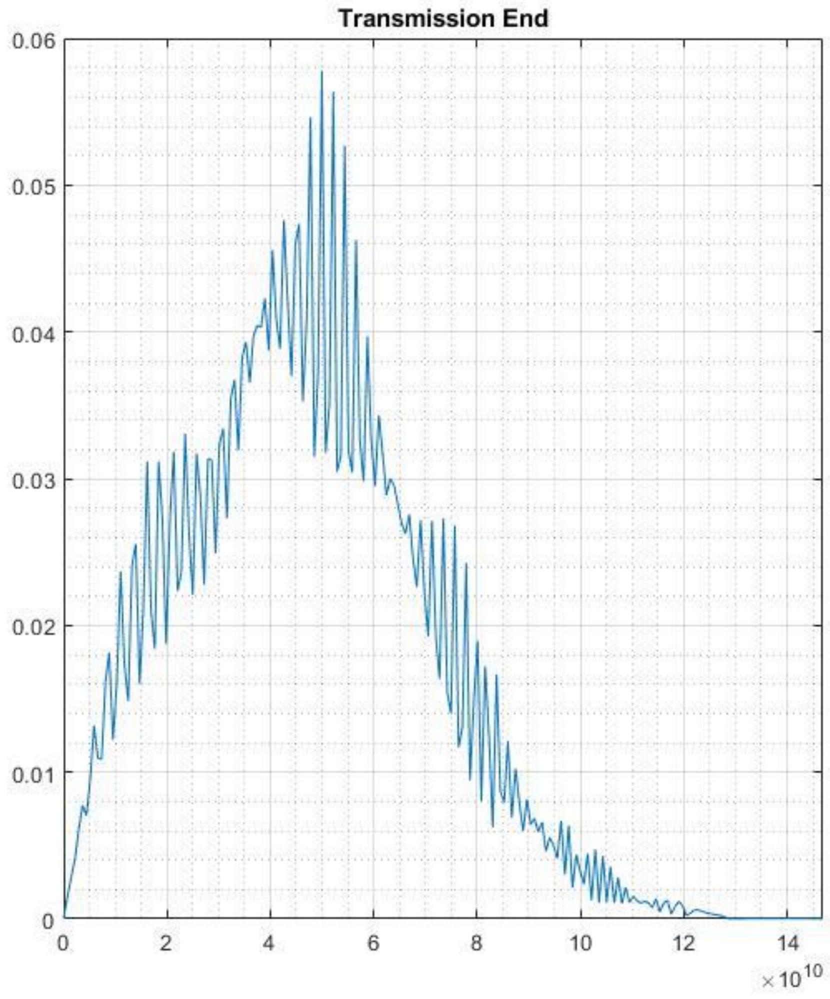
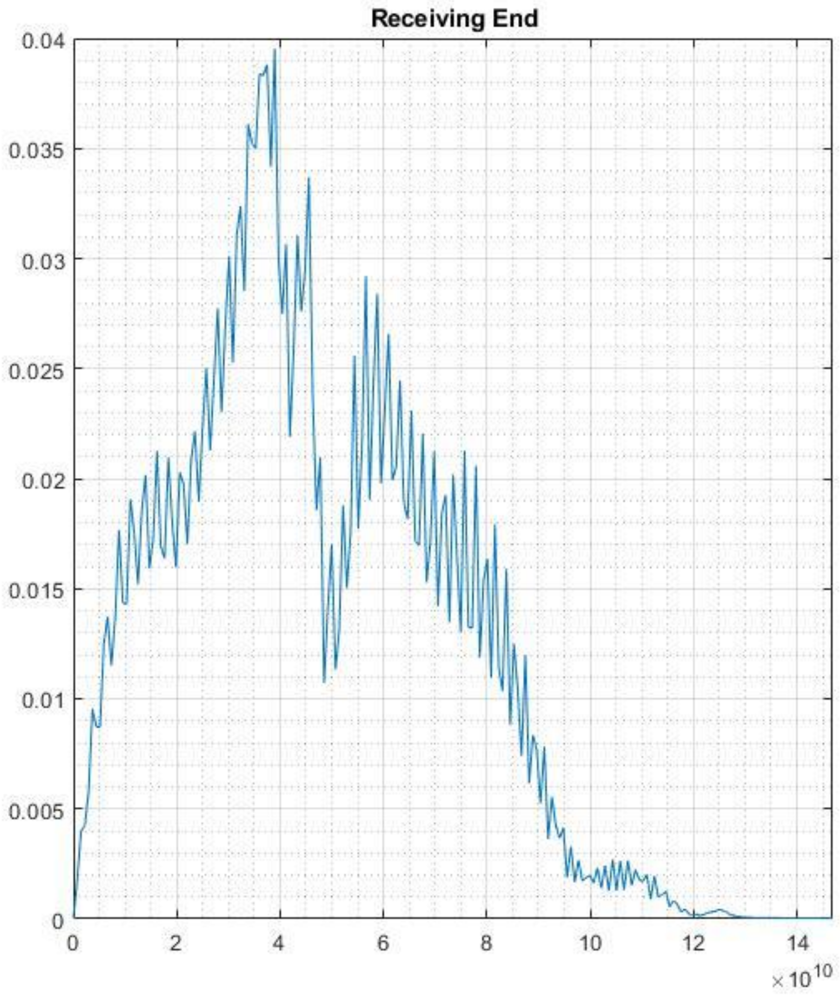
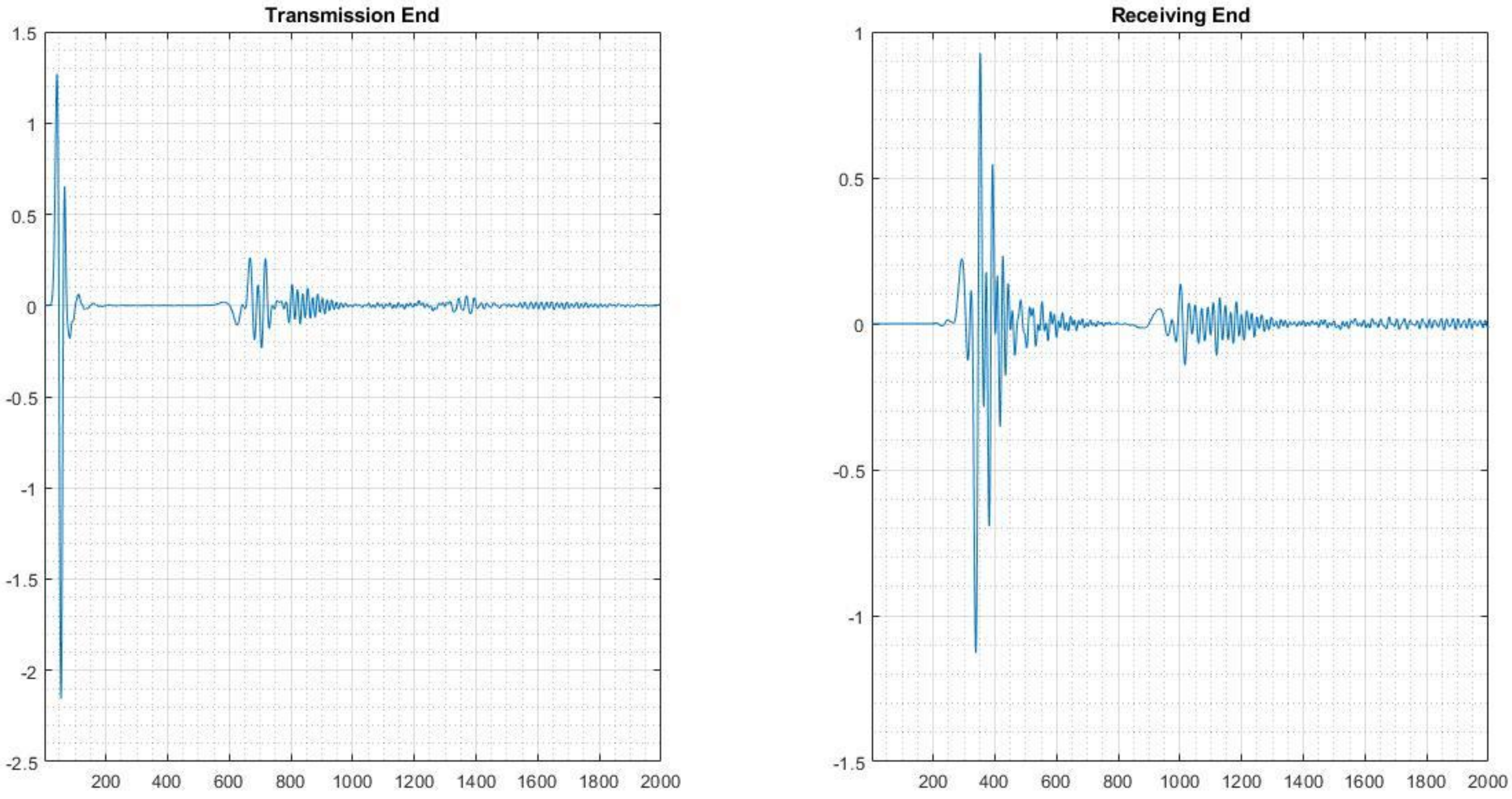




Current FFT

Gaussian modulated by a Sinusoidal Pulse (ν = 25 GHz)   [Air - 30 cells]



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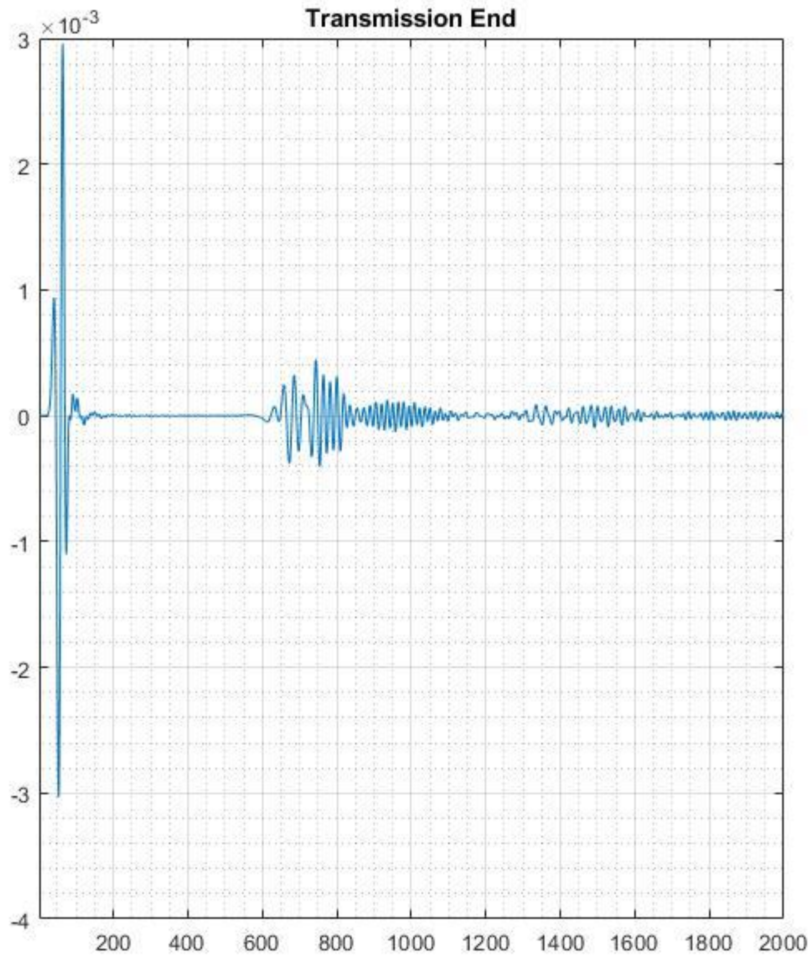

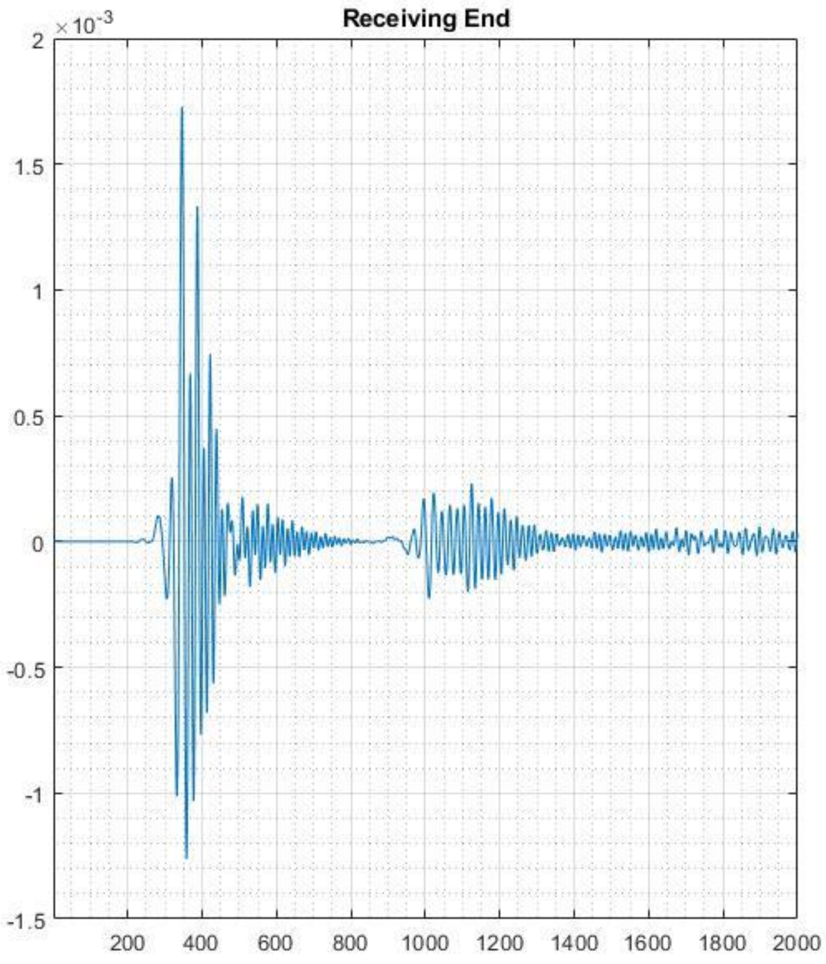

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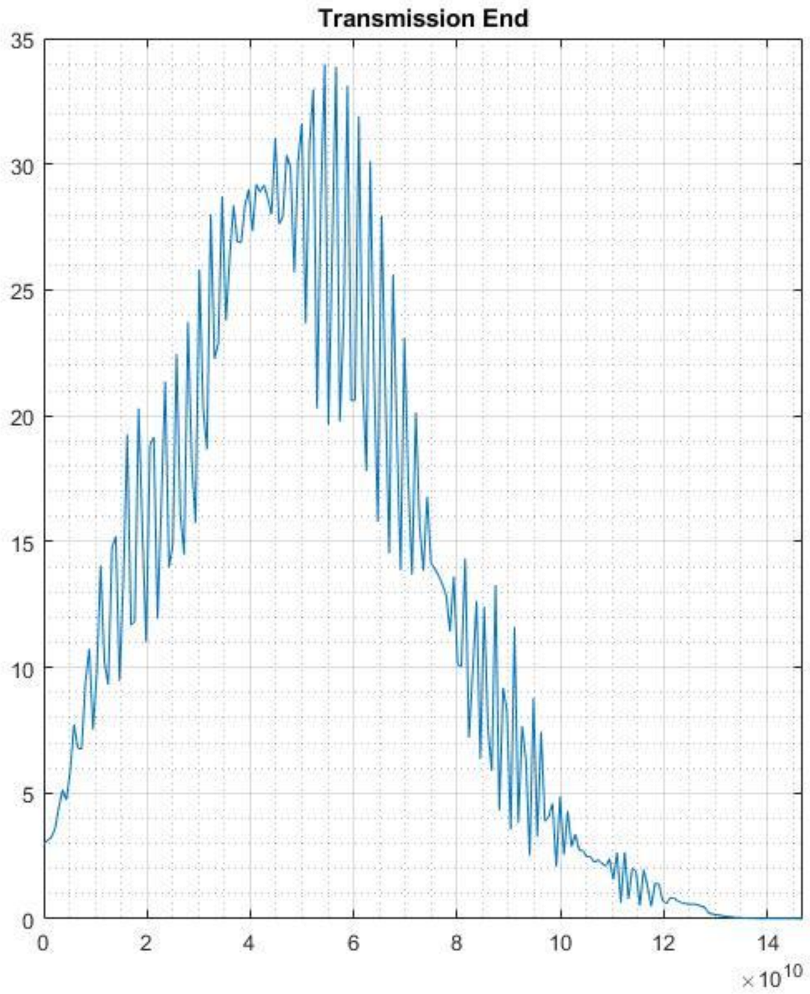

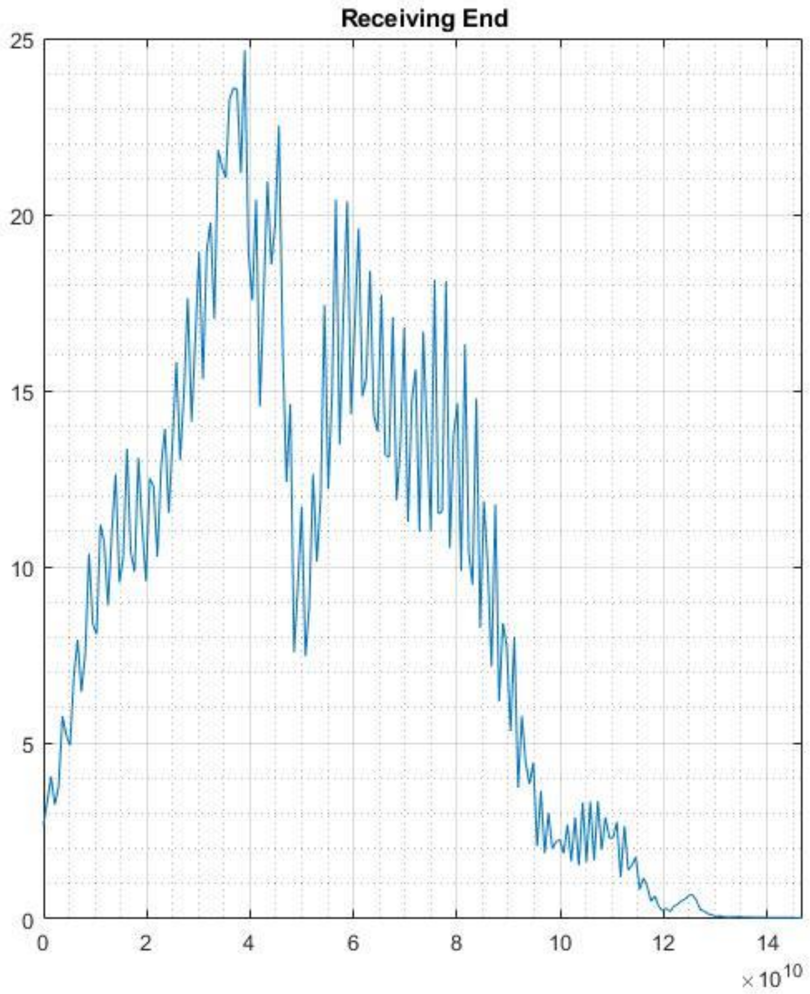

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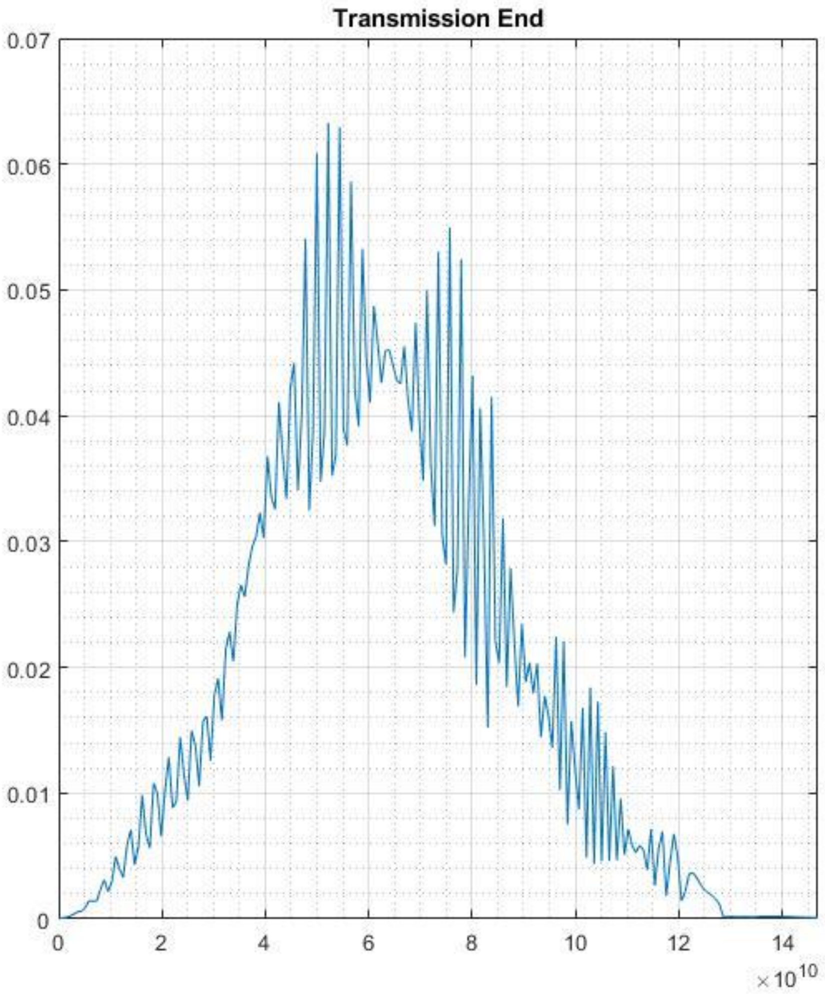

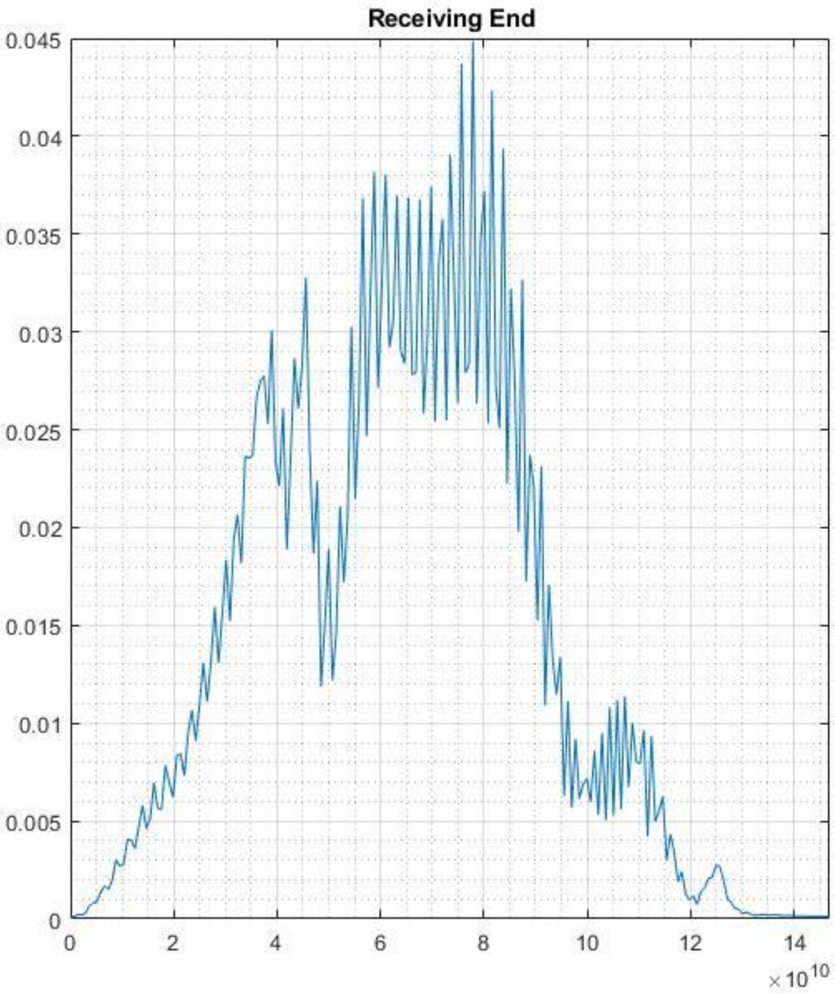

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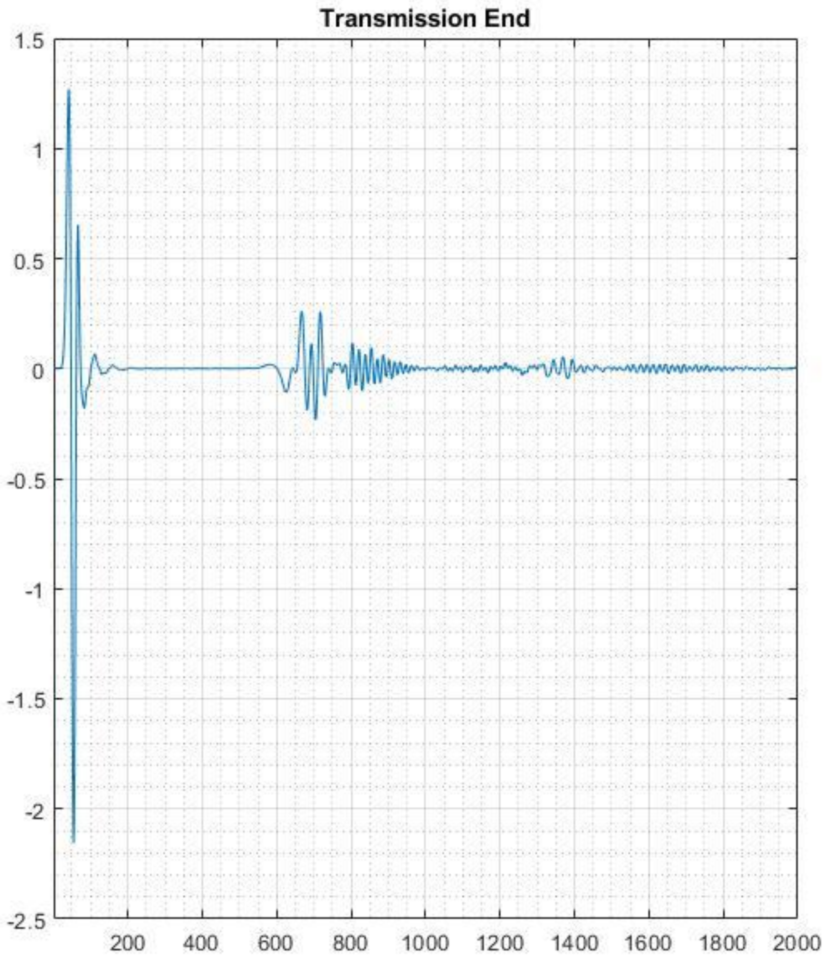

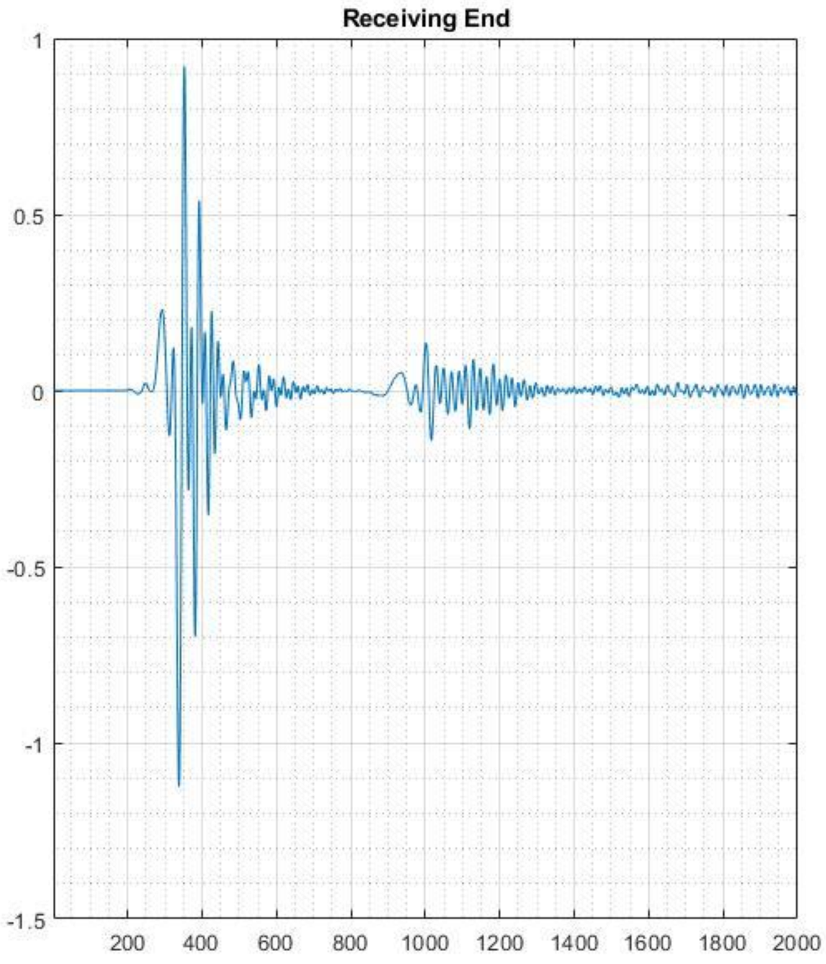

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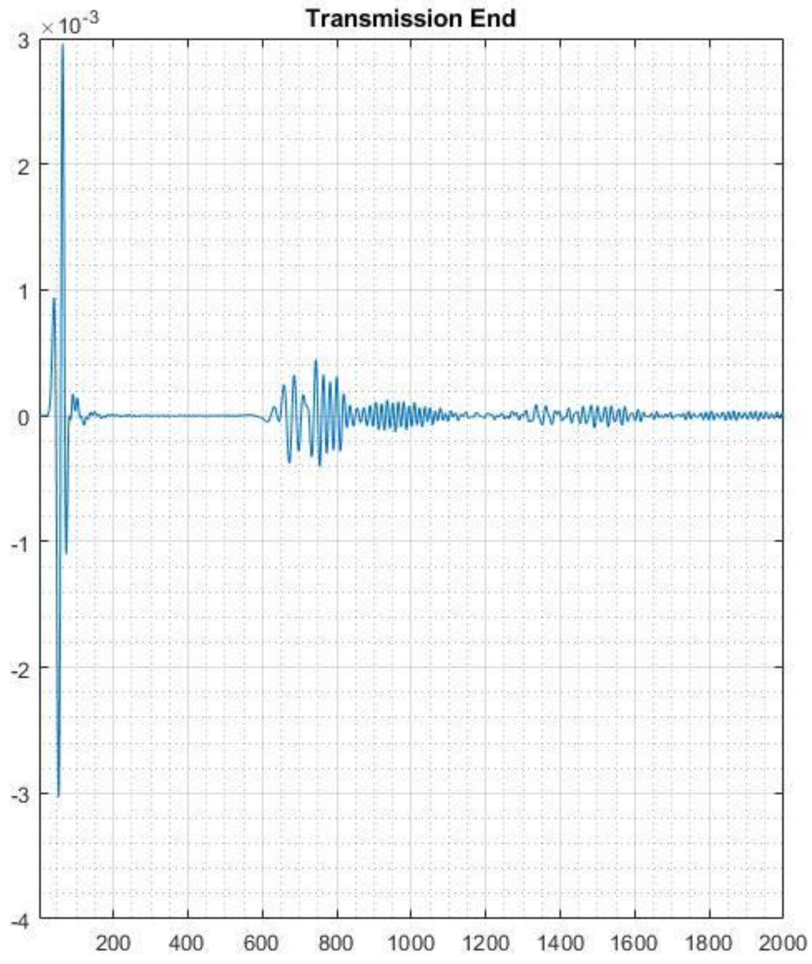

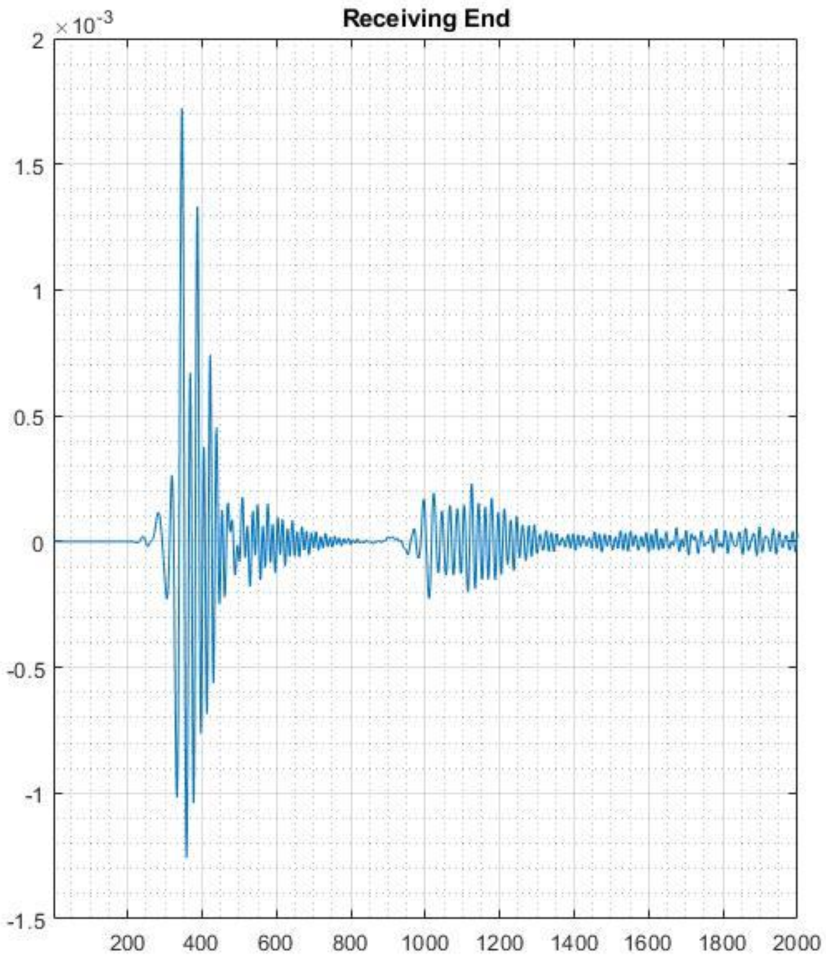

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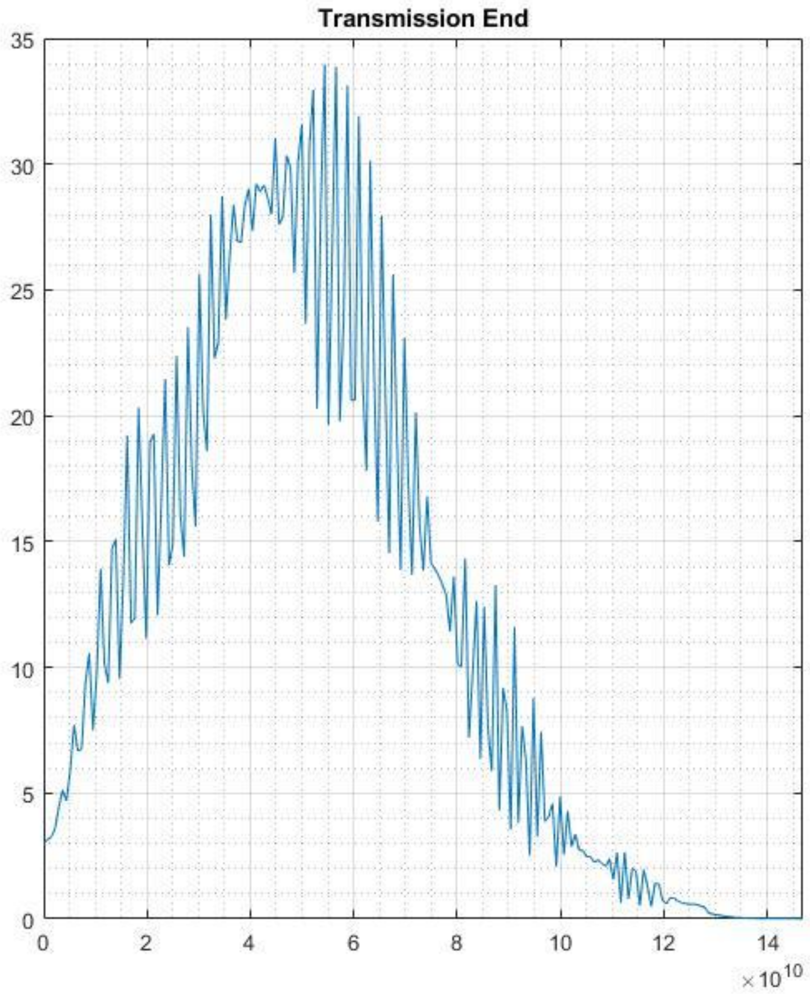

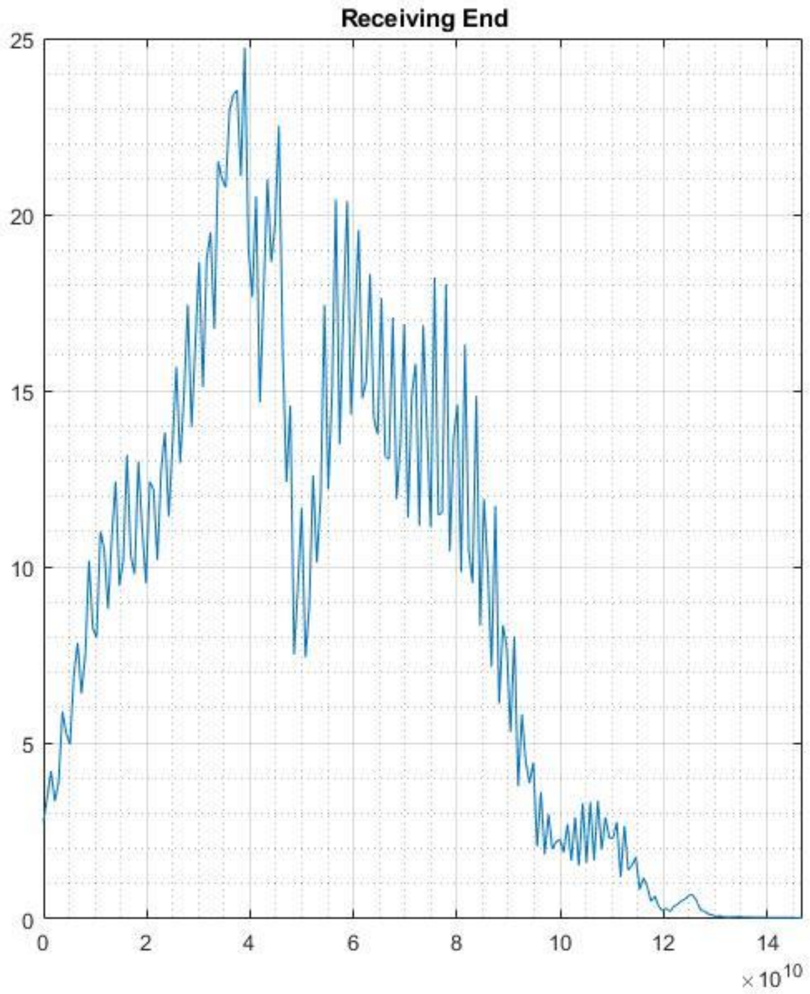

Voltage FFT

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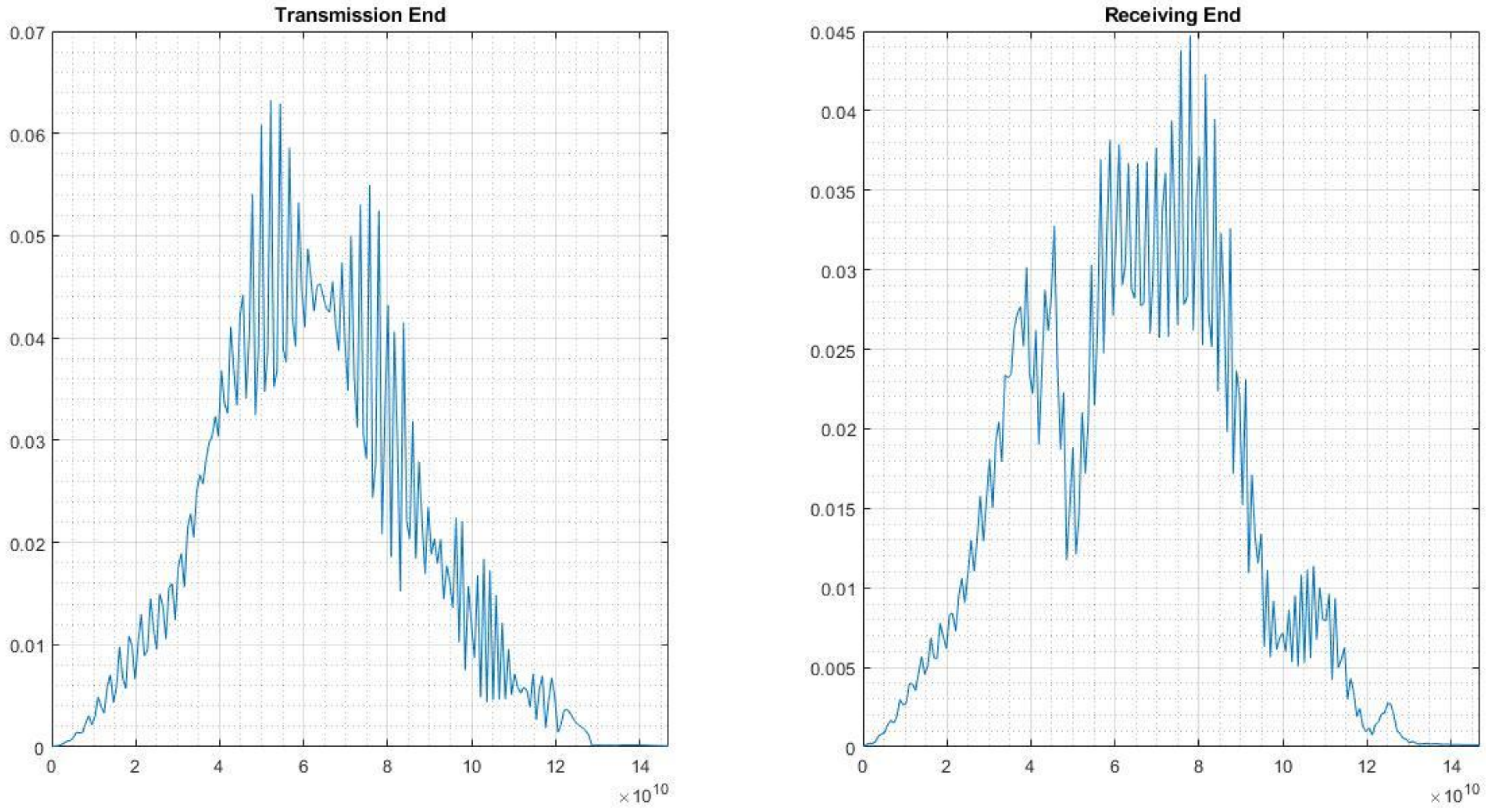

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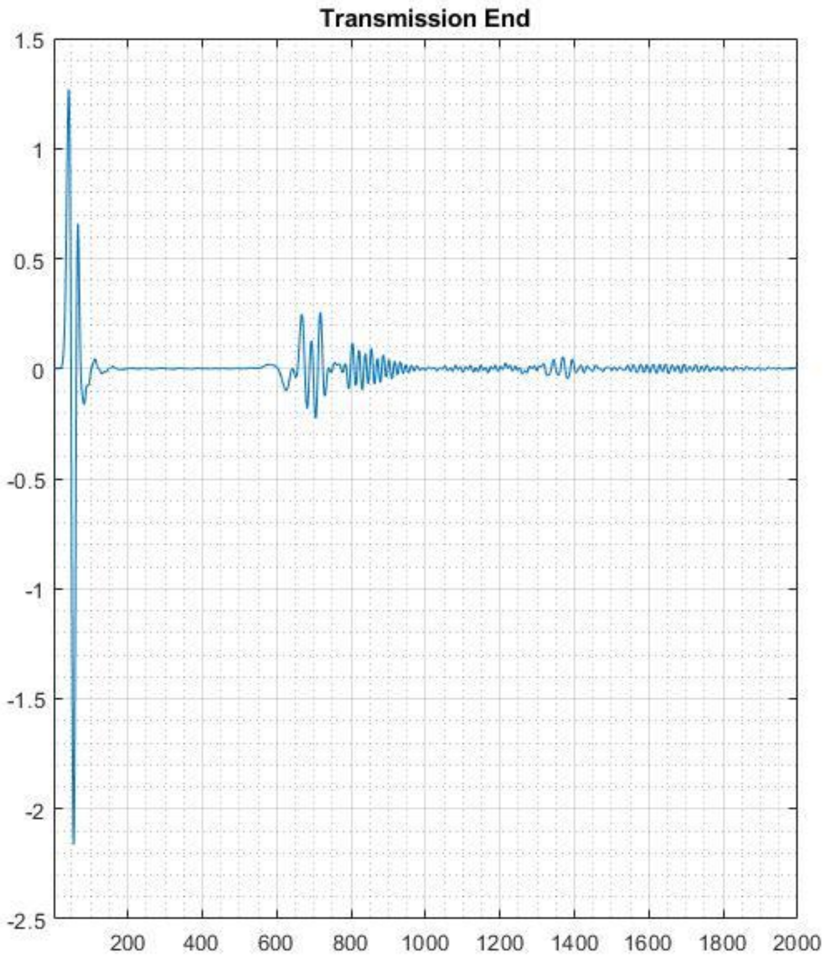
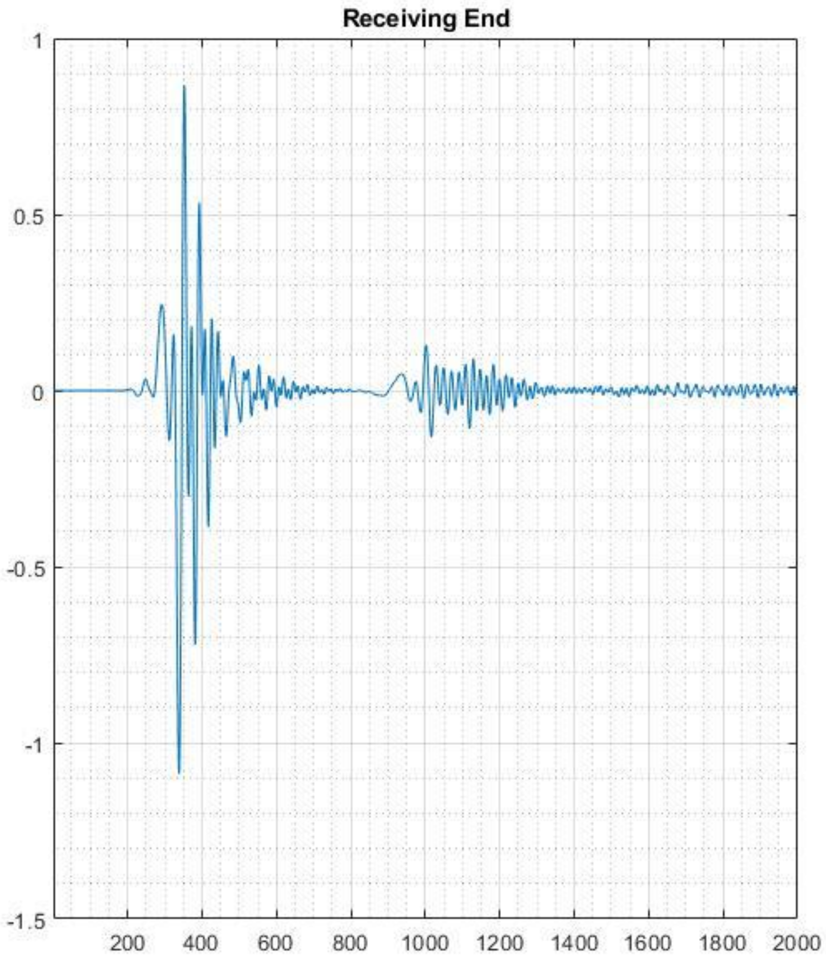
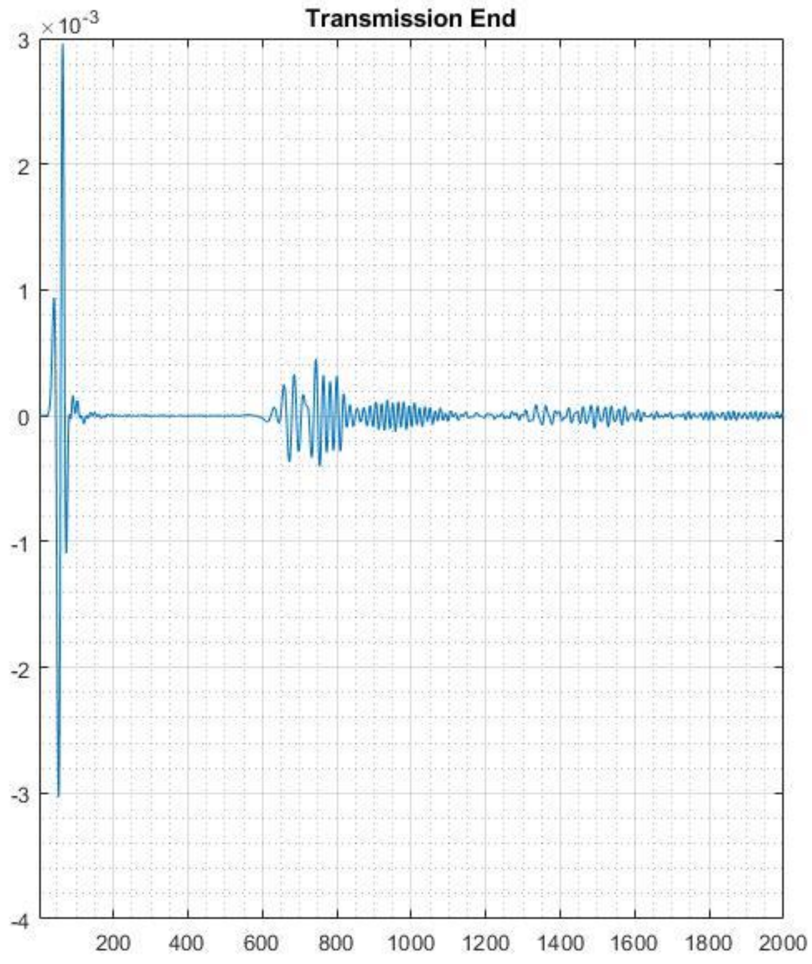
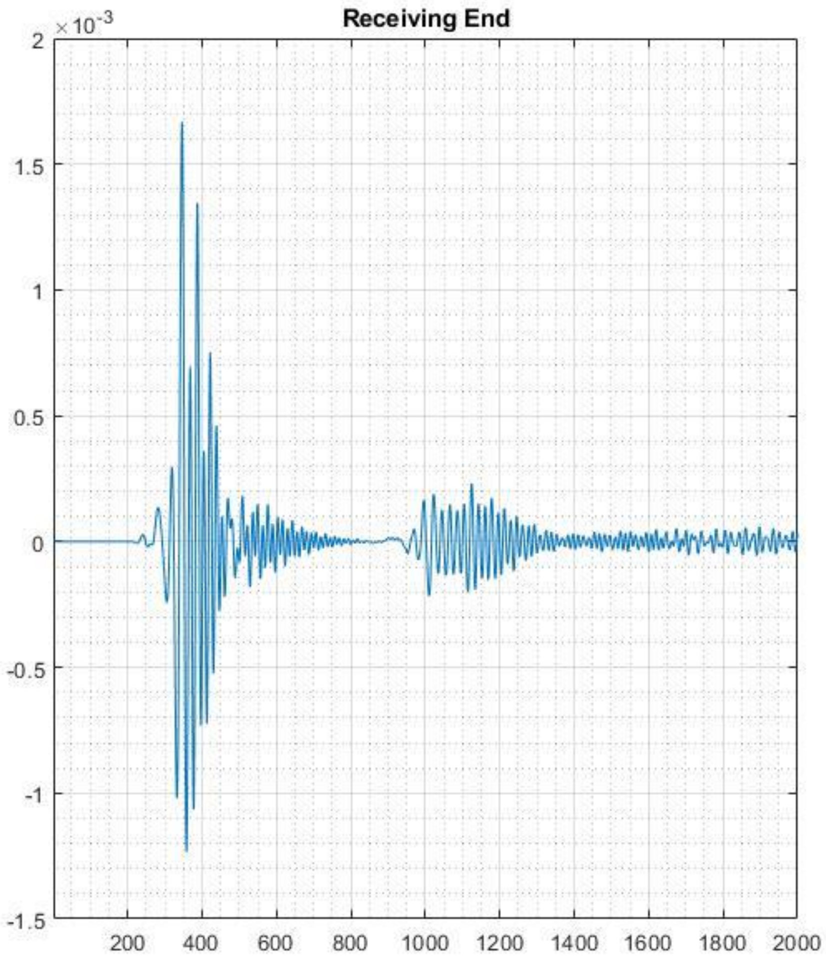




Voltage

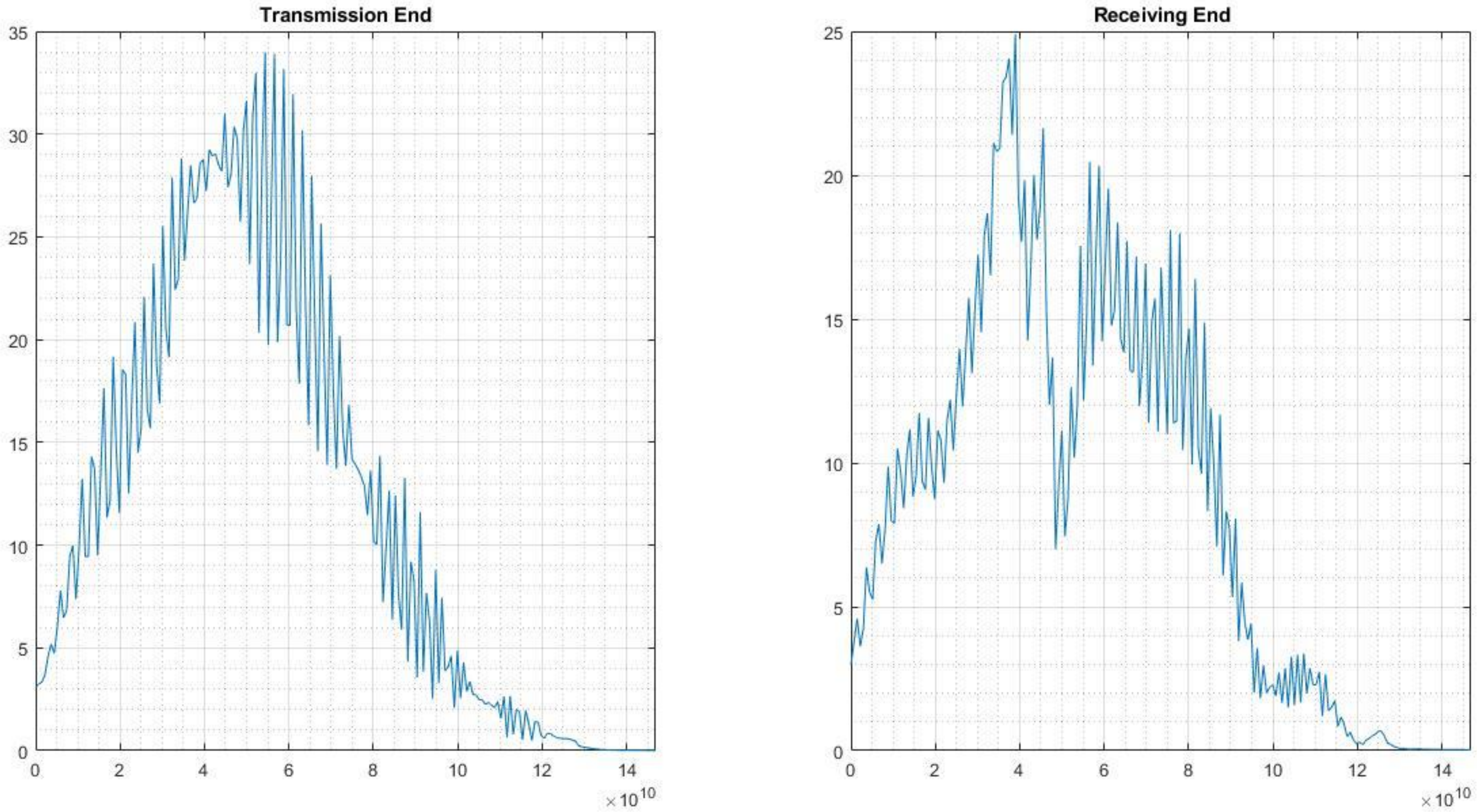
Gaussian modulated by a Sinusoidal Pulse (ν = 25 GHz) [Air - 10 cells]





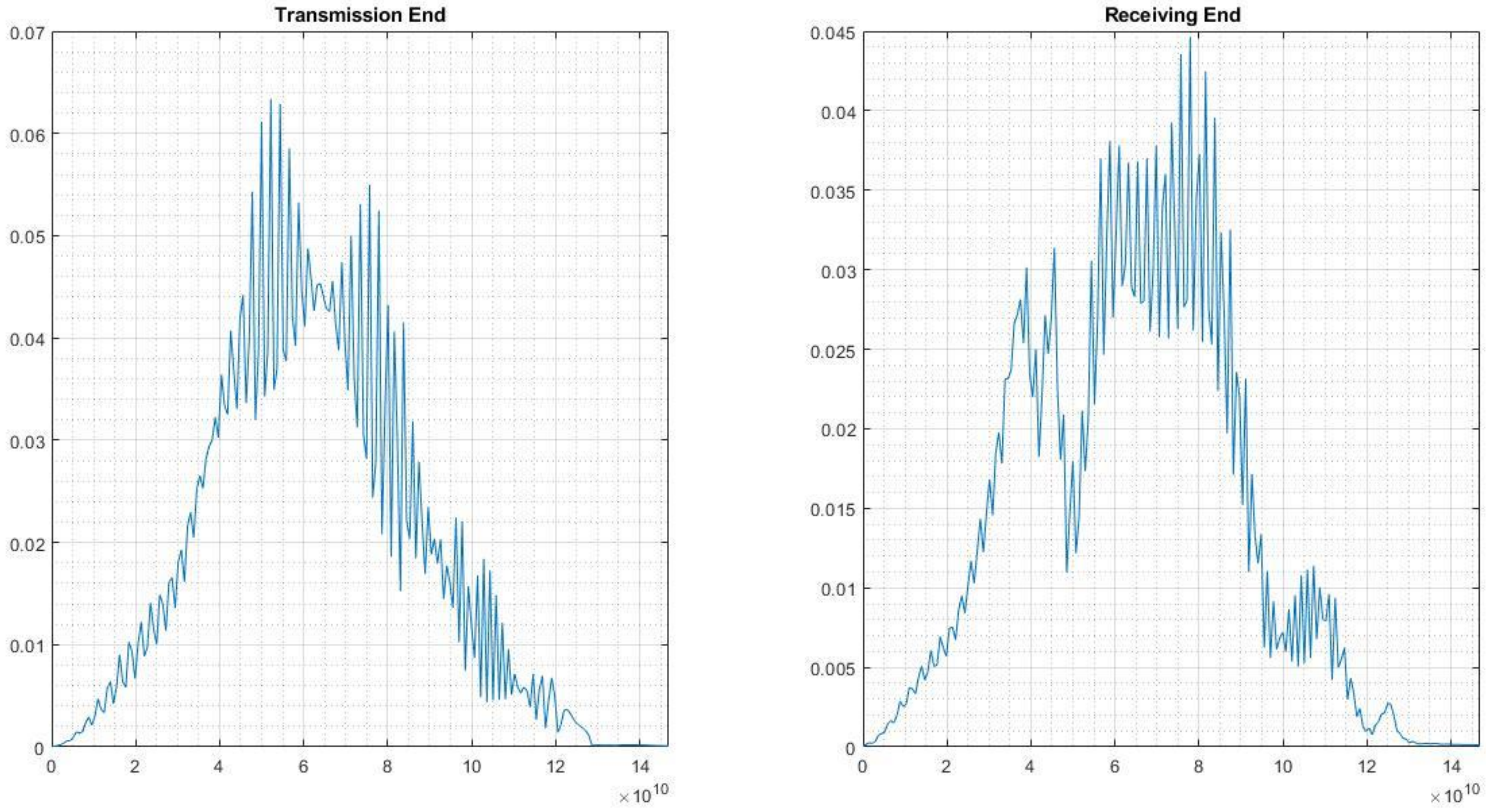
Current

Gaussian modulated by a Sinusoidal Pulse (ν = 25 GHz)   [Air - 10 cells]



Voltage FFT

Gaussian modulated by a Sinusoidal Pulse (ν = 25 GHz) [Air - 10 cells]



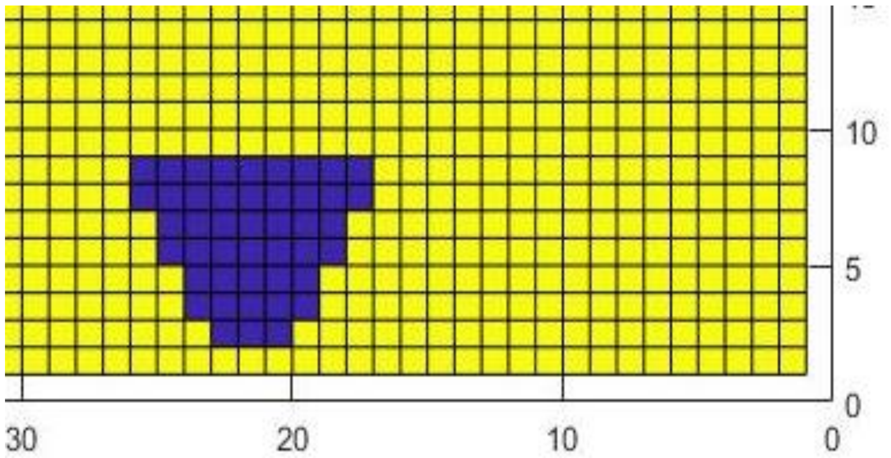
Current FFT

General Observations

- The peak frequencies at both the ends match with each other
- The voltage & current amplitudes at the receiving end increase with decreasing air column height
- For the modulated gaussian pulses, the FFT plots shift towards the right by a frequency equal to that of the multiplied sin wave
- Initially, the voltage calculation and ampere's law codes were written after the E-H update equations. The amplitude shot up to ∞
- This instability was removed by shifting the block of code before the source is illuminated

Luebber’s Source Tapering

- Eliminates the need to illuminate the entire source, thus speeding up calculations



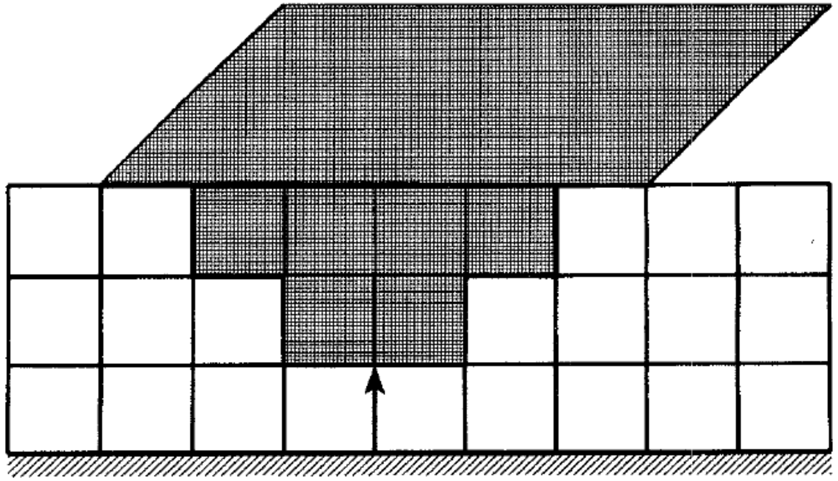


Fig. 3. Detail of staircased FDTD mesh transition from the electric field-source location to the full width of the microstrip feed to the patch antenna.

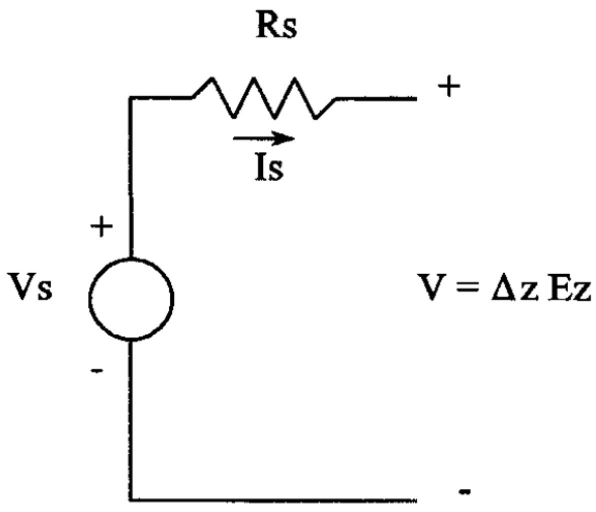
```
gx(strip_xl1+1:strip_xl2-1,feed_y2-1:feed_y2,feed_zl) = 0;
gx(strip_xl1+2:strip_xl2-2,feed_y2-3:feed_y2-2,feed_zl) = 0;
gx(strip_xl1+3:strip_xl2-3,feed_y2-5:feed_y2-4,feed_zl) = 0;
gx(strip_xl1+4:strip_xl2-4,feed_y2-6,feed_zl) = 0;

gy(strip_xl1+1:strip_xl2-1,feed_y2-1:feed_y2,feed_zl) = 0;
gy(strip_xl1+2:strip_xl2-2,feed_y2-3:feed_y2-2,feed_zl) = 0;
gy(strip_xl1+3:strip_xl2-3,feed_y2-5:feed_y2-4,feed_zl) = 0;
gy(strip_xl1+4:strip_xl2-4,feed_y2-6,feed_zl) = 0;
```

Luebber's Input Source Implementation

- Source modelled with an Input Impedance

$$E_s^n(i_s, j_s, k_s) = V_s(n\Delta t)/\Delta z + I_s^{n-1/2} R_s/\Delta z$$

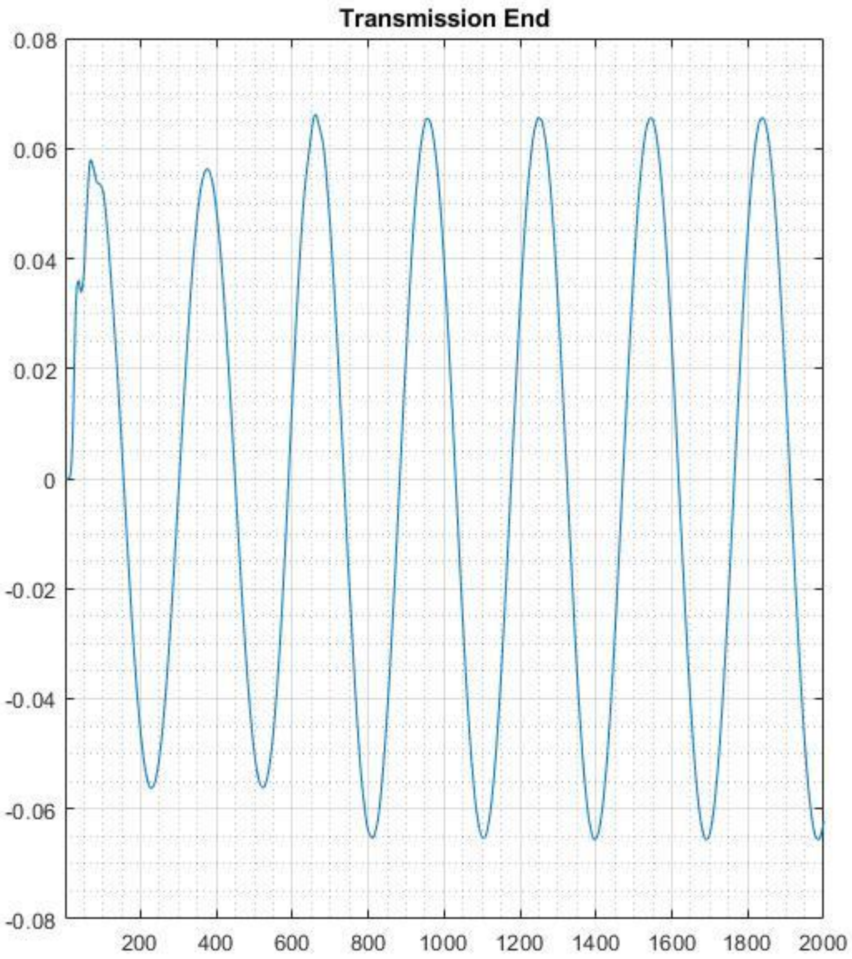
- If R_s = 0, the usual hard voltage source results

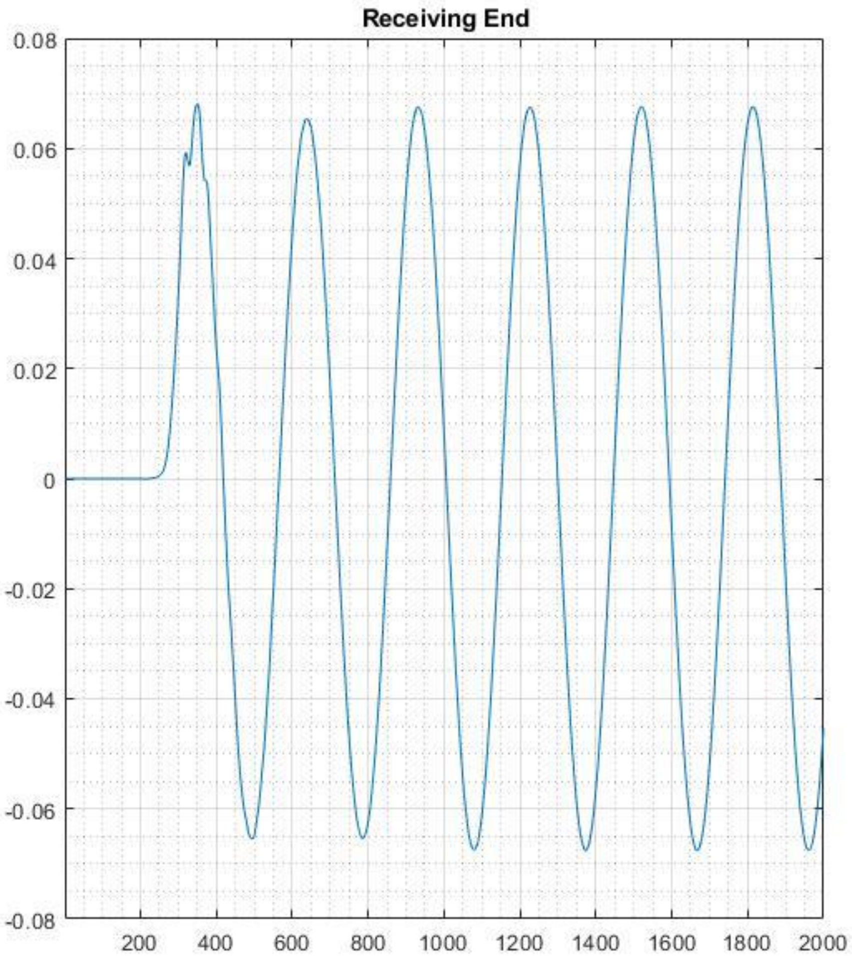


FDTD source with source resistance R_s.

```
% ----- Sinusoidal signal of 5 GHz---------
pulse = sin(2*pi*5e9*time);
ey(feed_x,feed_y,feed_z1) = (pulse/dy) + ((transmit_Current(count)*Zs)/dy);
```

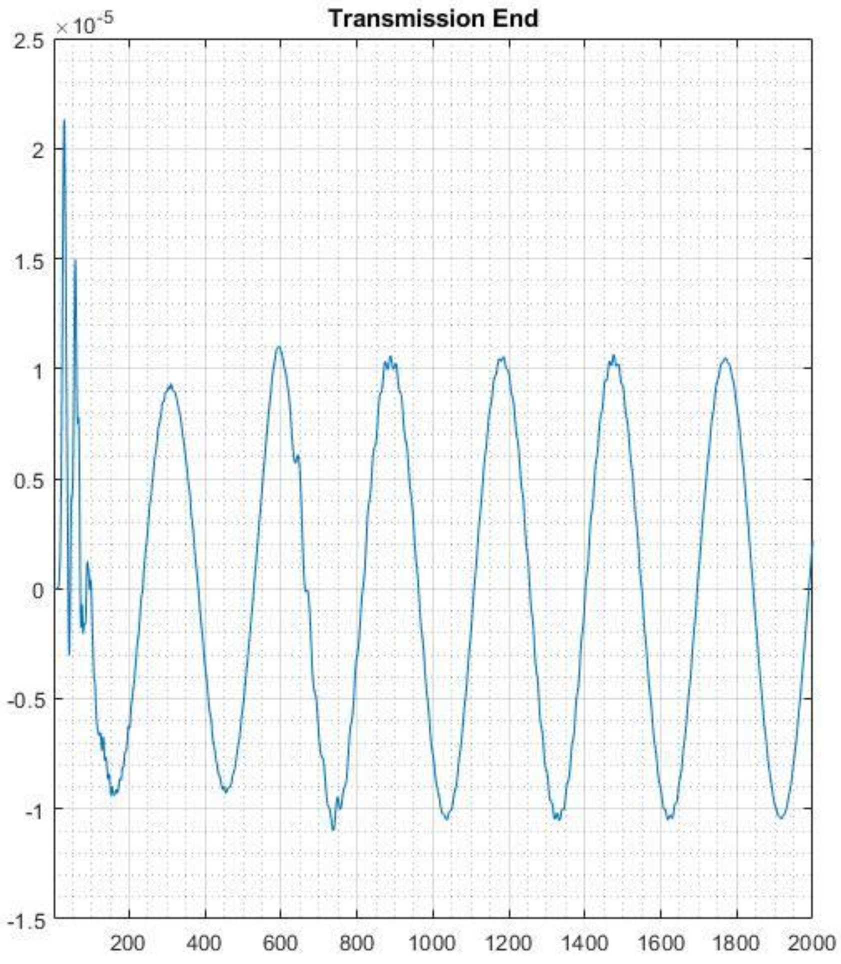
Sinusoidal Pulse with Luebber's Source & Tapering [air - 30 cells]

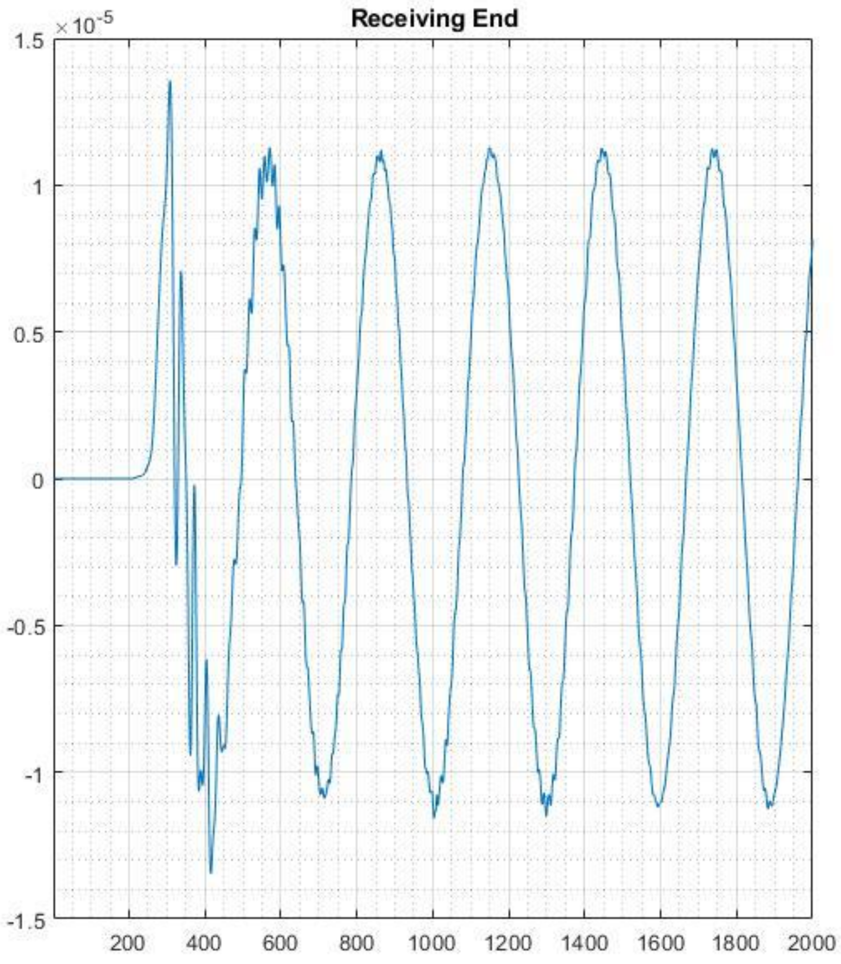




Voltage

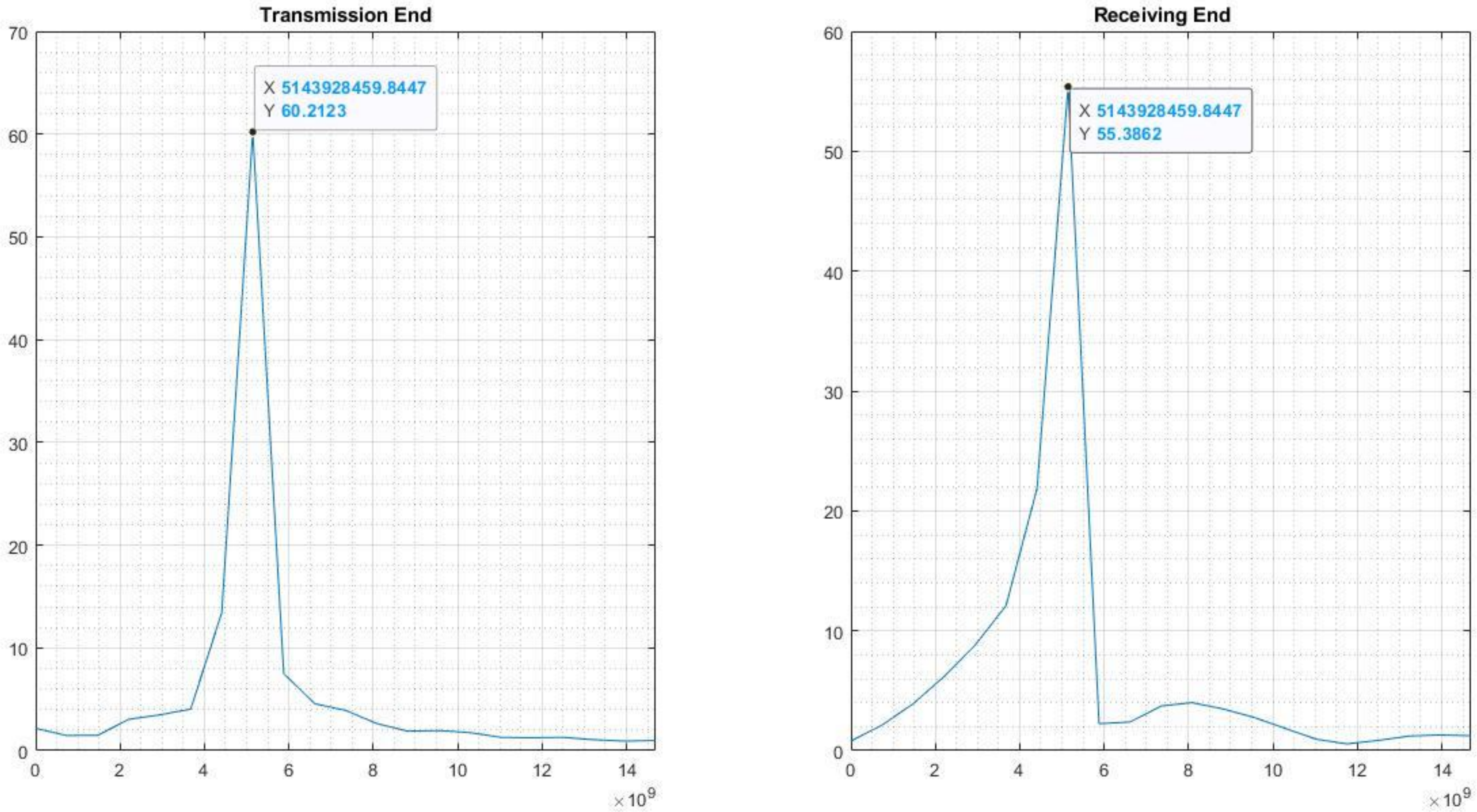
Sinusoidal Pulse with Luebber’s Source & Tapering [air - 30 cells]





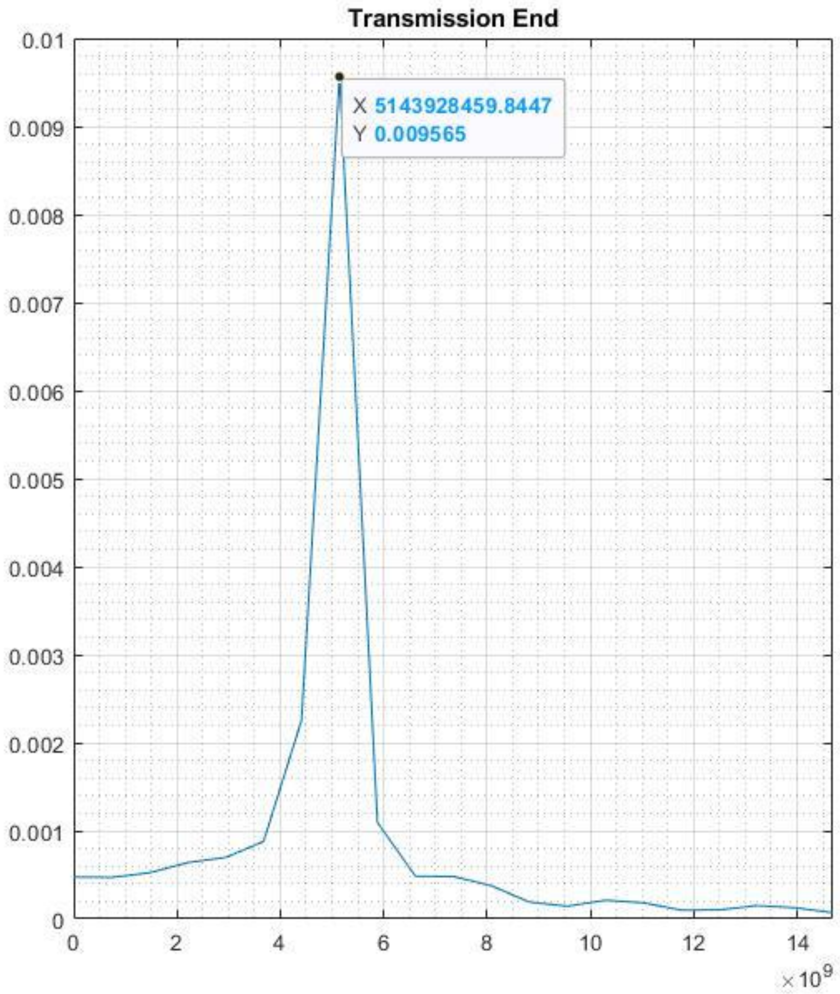
Current

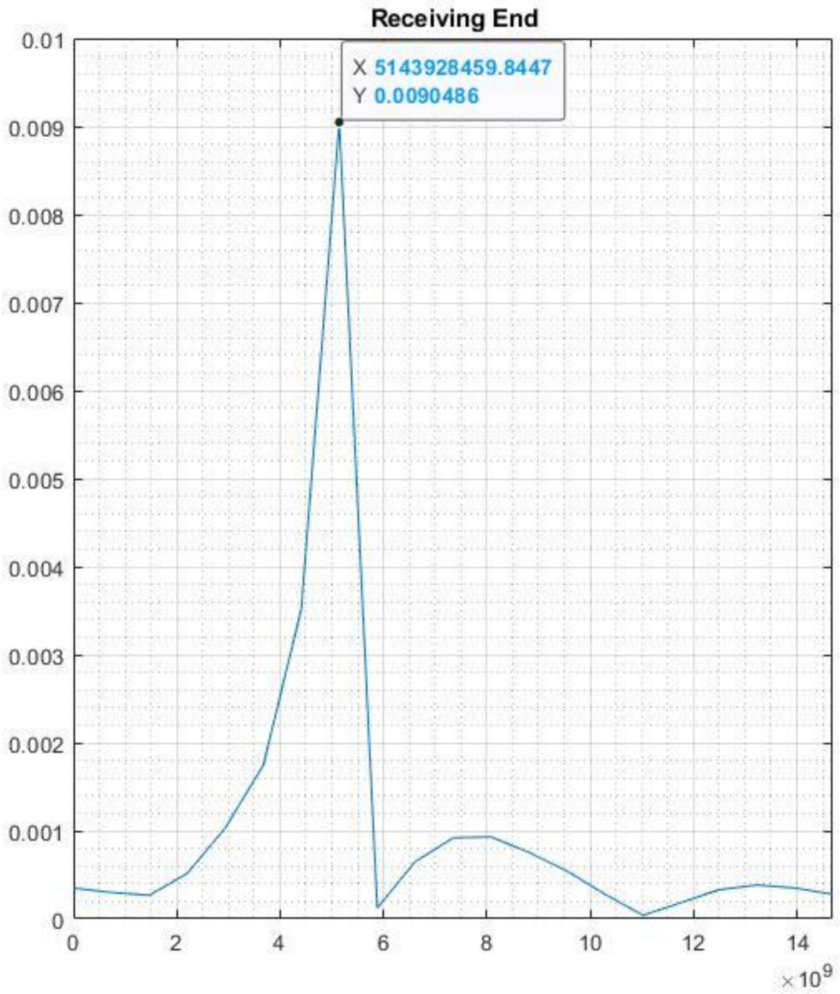
Sinusoidal Pulse with Luebber's Source & Tapering [air - 30 cells]



Voltage FFT

Sinusoidal Pulse with Luebber's Source & Tapering [air - 30 cells]

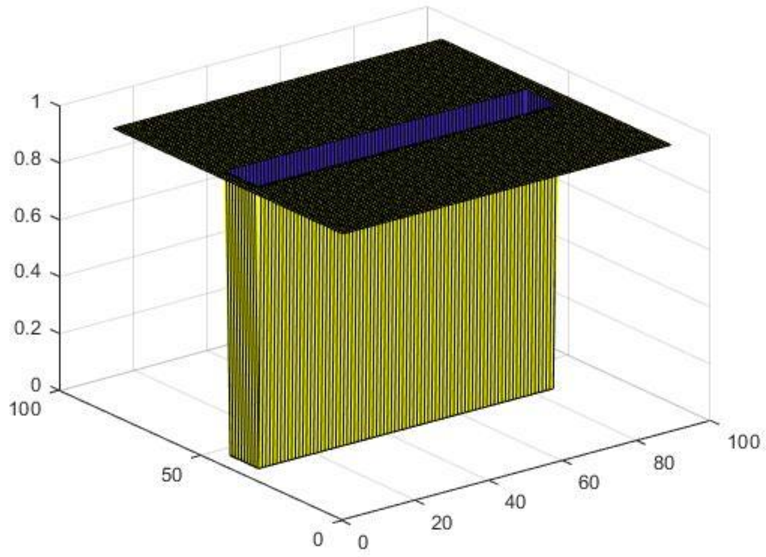




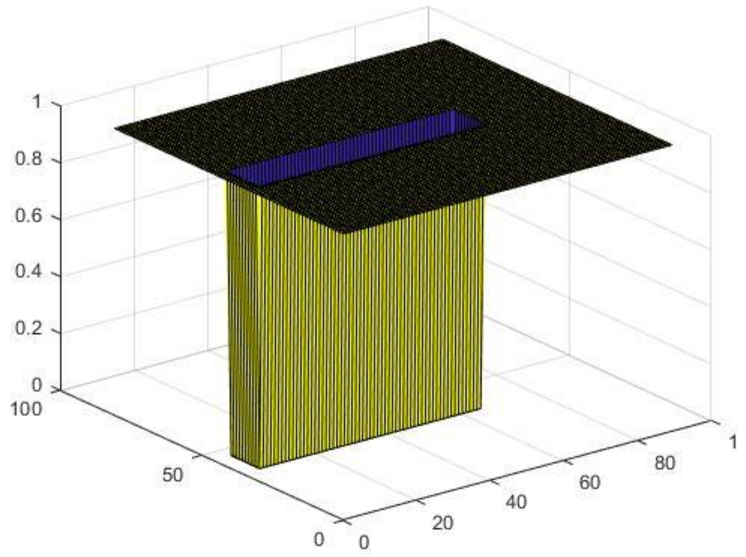
Current FFT

Truncated Microstrip line

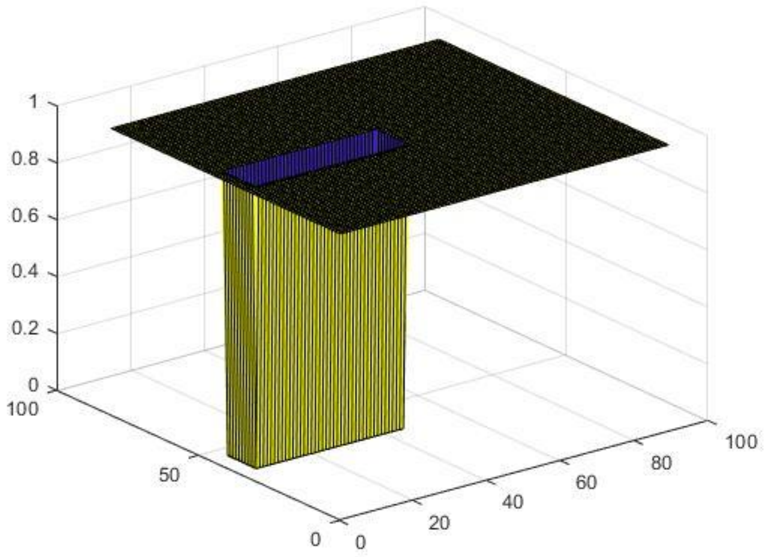
- Length of Microstrip reduced in discrete steps to compare S_{11} plots in each case
- Substrate dimensions - 40 mm X 40 mm | dx = dz = 0.5e-03, dy = dx/2



40 mm



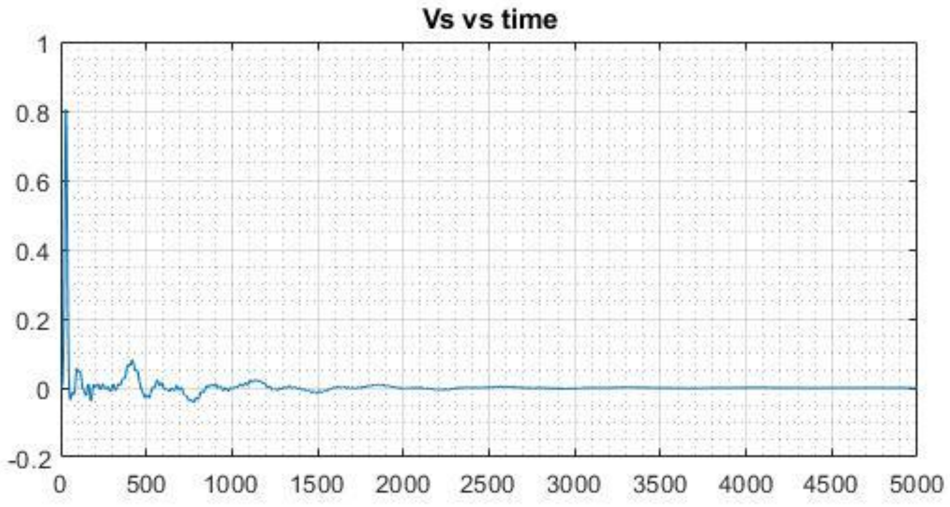
30 mm

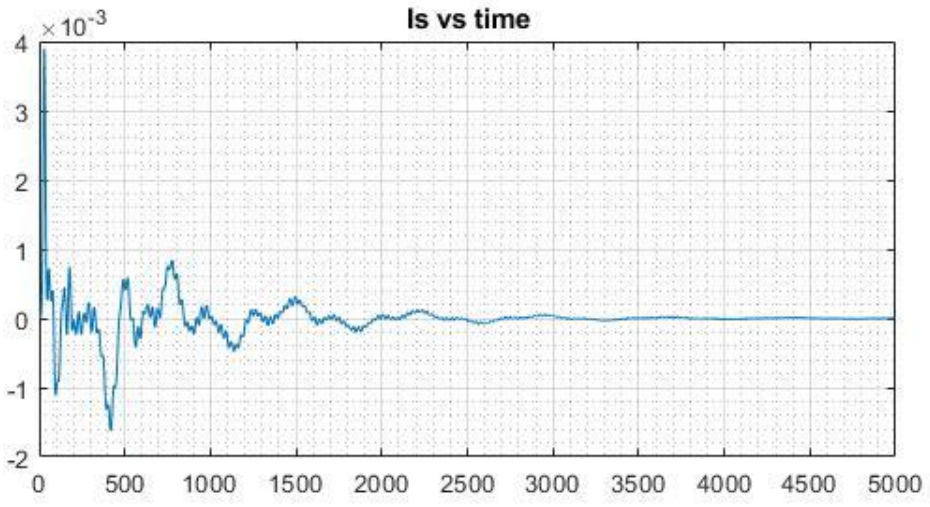


20 mm

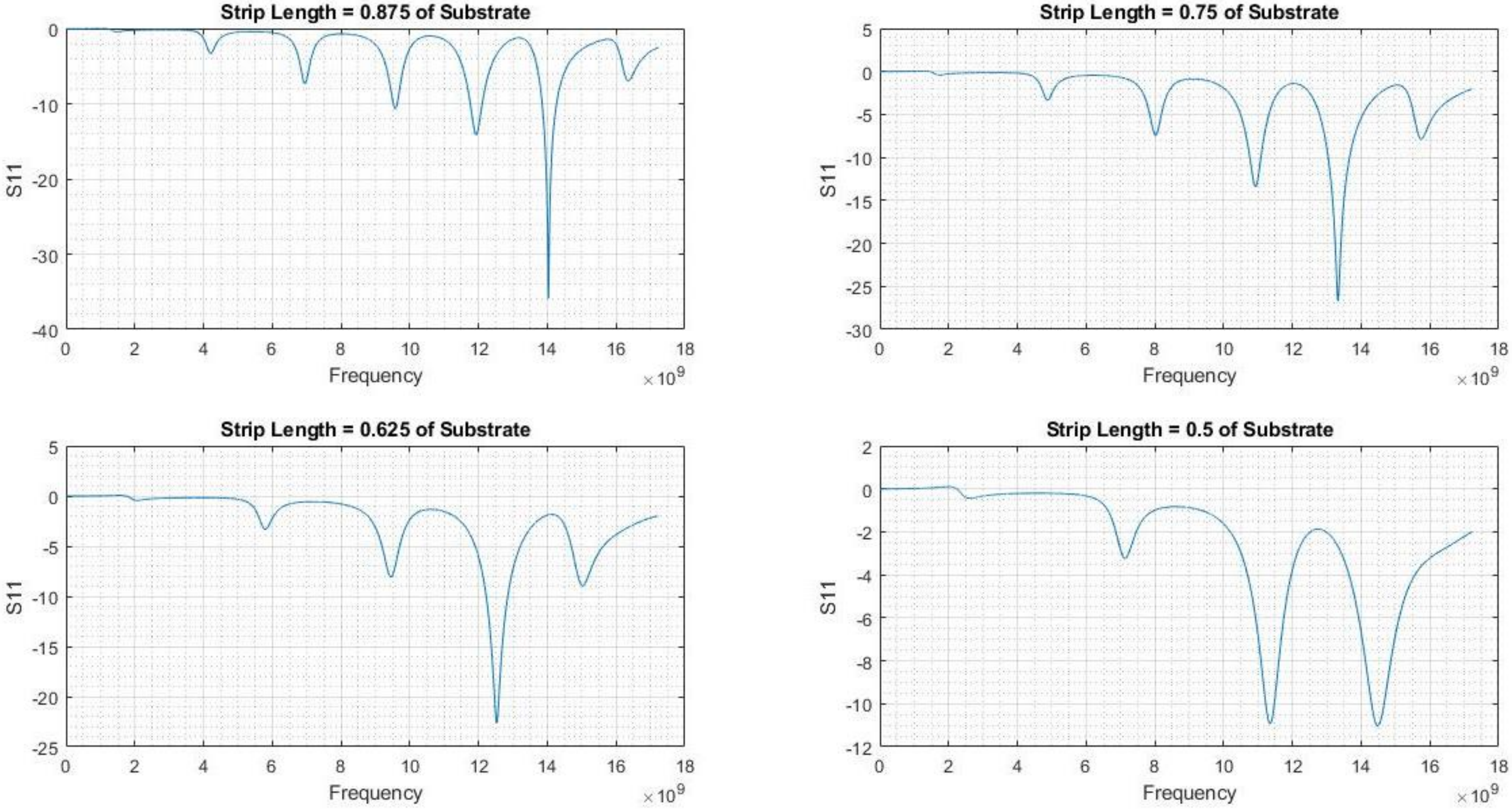
Truncated Microstrip line

- Z_{in} = fft(volt_in, Nmax) ./ fft(curr_in, Nmax)
- S_{11} = 20*log10(abs((Z_{in} - Z_s) ./ (Z_{in} + Z_s))) | $Z_s = 50\ \Omega$
- Simulation run for 5000 counts





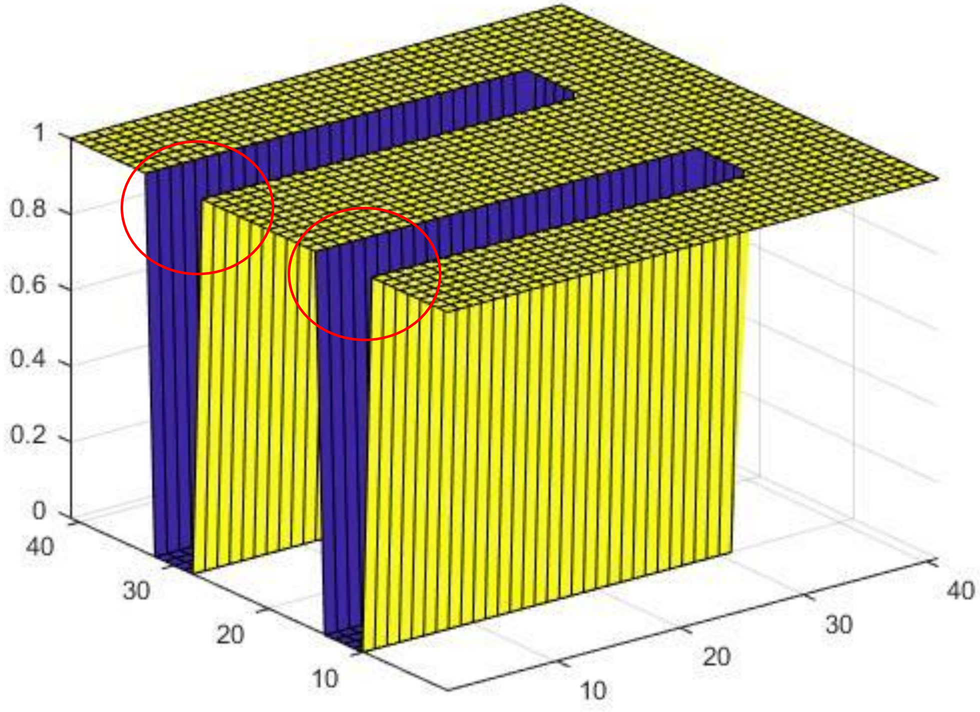
S_{11} plots



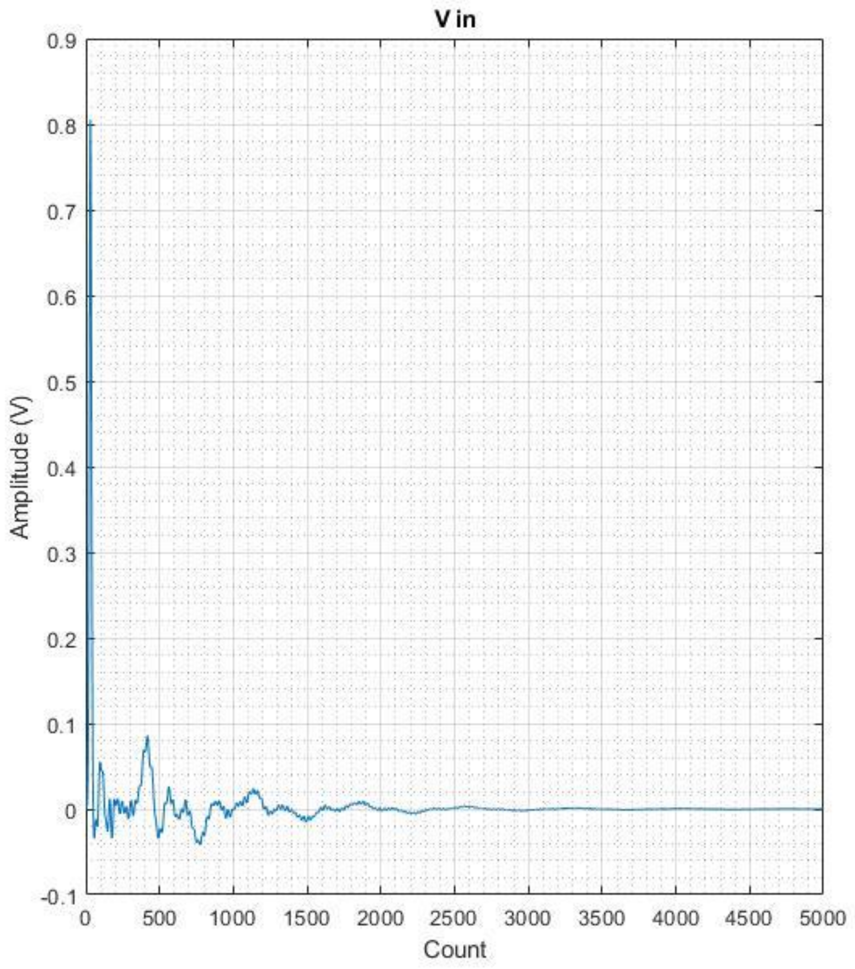
Strip Length = 0.875 of Substrate
S11
Frequency
×10^9
Strip Length = 0.75 of Substrate
S11
Frequency
×10^9
Strip Length = 0.625 of Substrate
S11
Frequency
×10^9
Strip Length = 0.5 of Substrate
S11
Frequency
×10^9

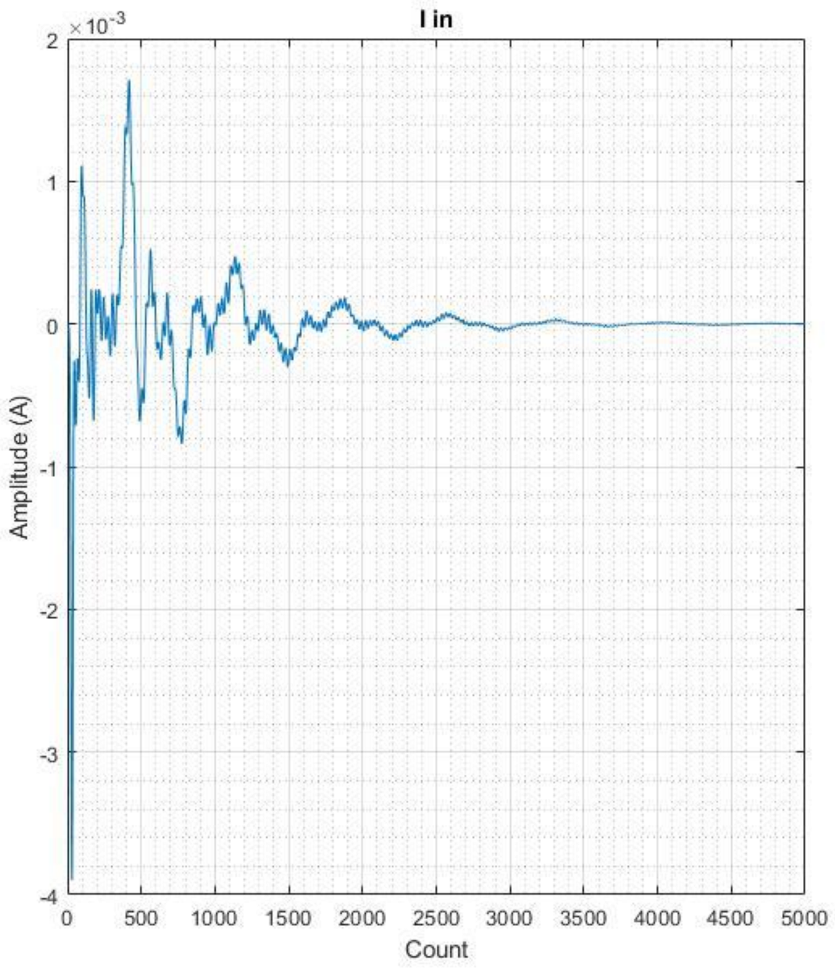
Response of Two Truncated Microstrip lines

- Substrate dimensions - 40 mm X 40 mm
- Feed point - 3 cells inwards
- Stripline length = 30mm
- dx = dz = 1e-03, dy = dx/2
- Source illuminated at input port of strip 1 & output taken at strip 2



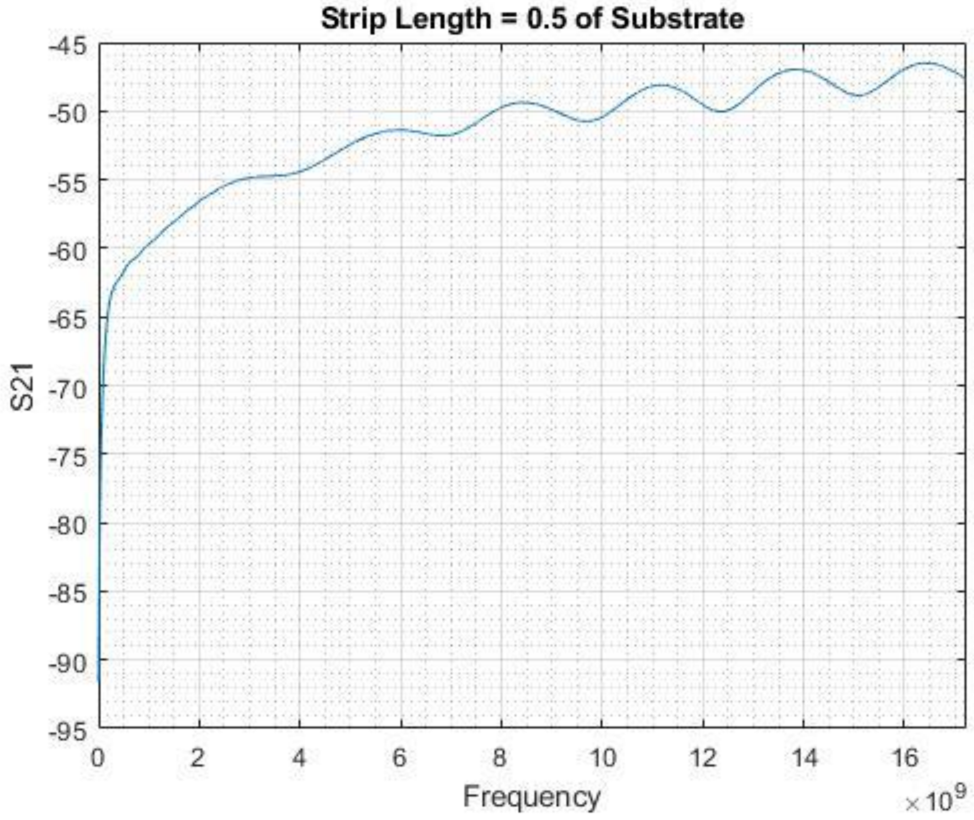
Voltage & Current at Input Port



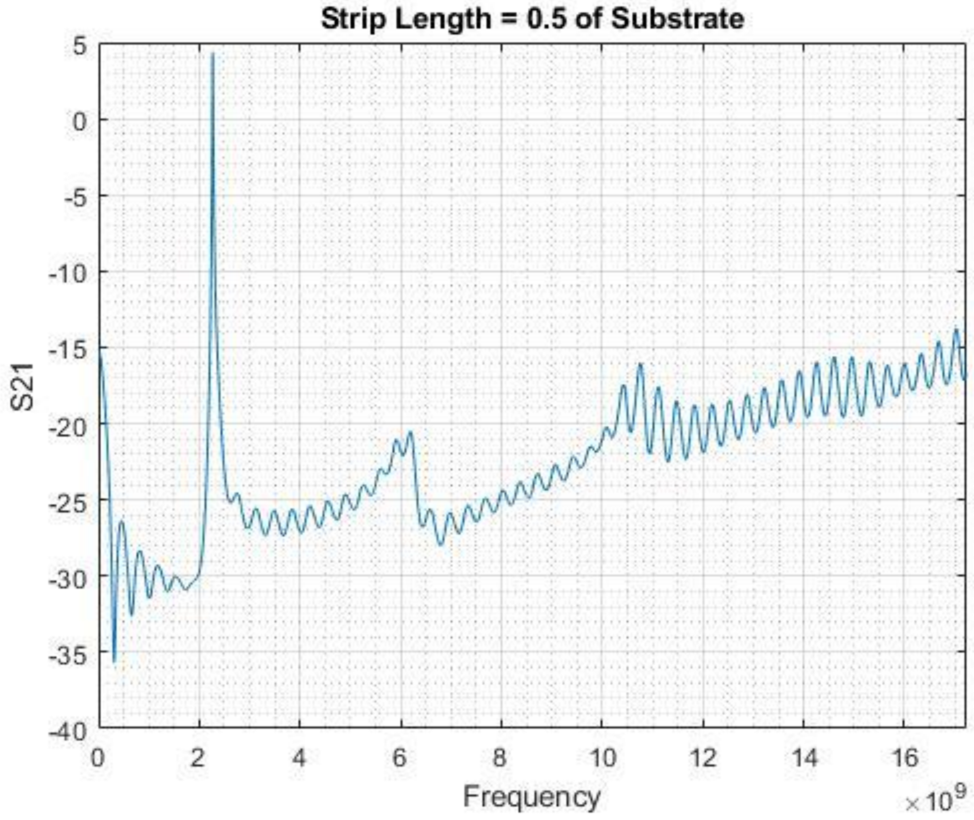


S_{21} = 20*log10(abs(fft(volt_out) ./ fft(volt_in)))

S_{21} plots change with variation in Air column height (y_off)

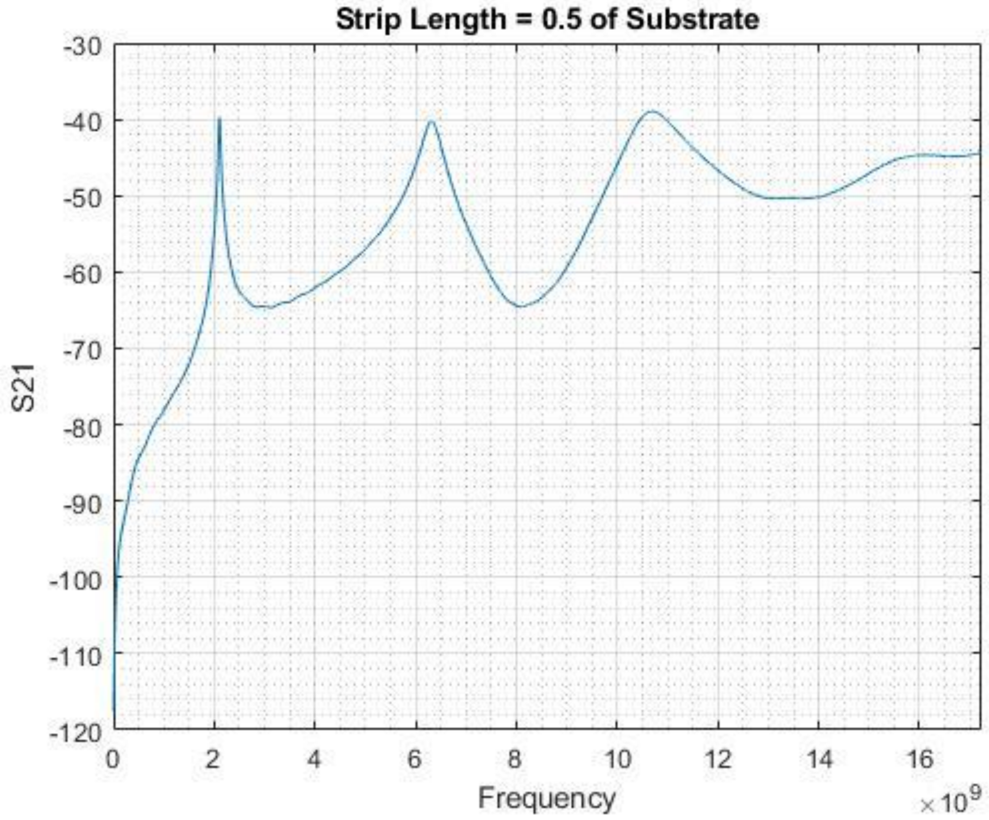


y_off = 0 cells

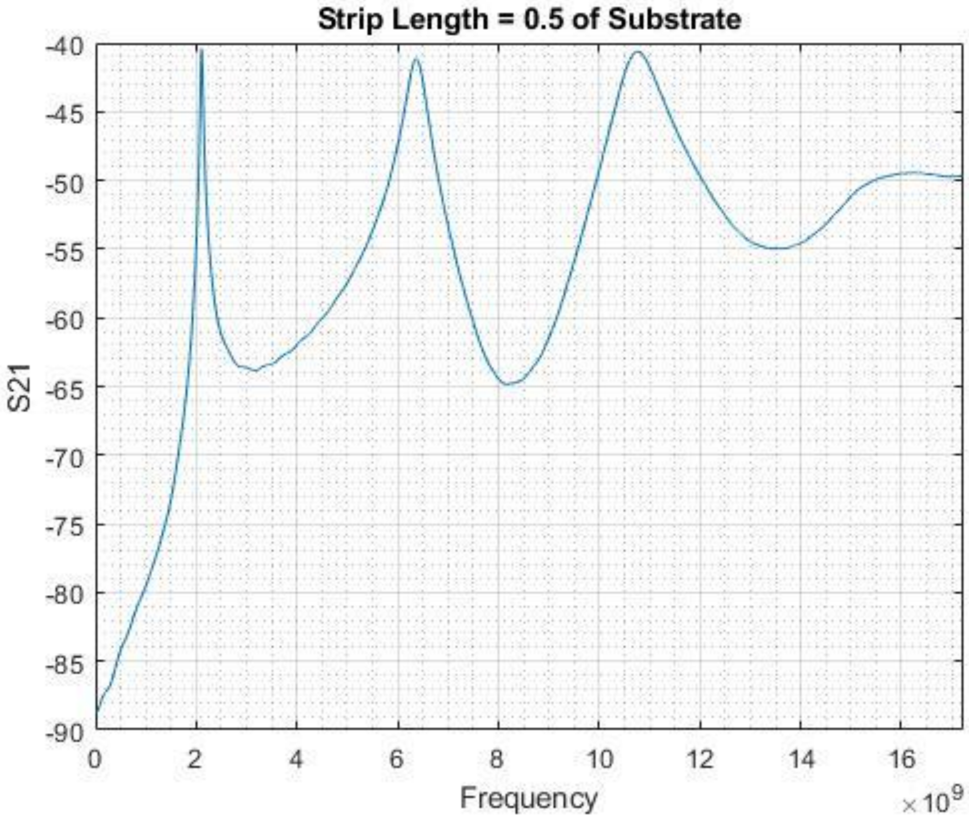


y_off = 7 cells

Beyond y_off = 10, solution is stable, and change is negligible

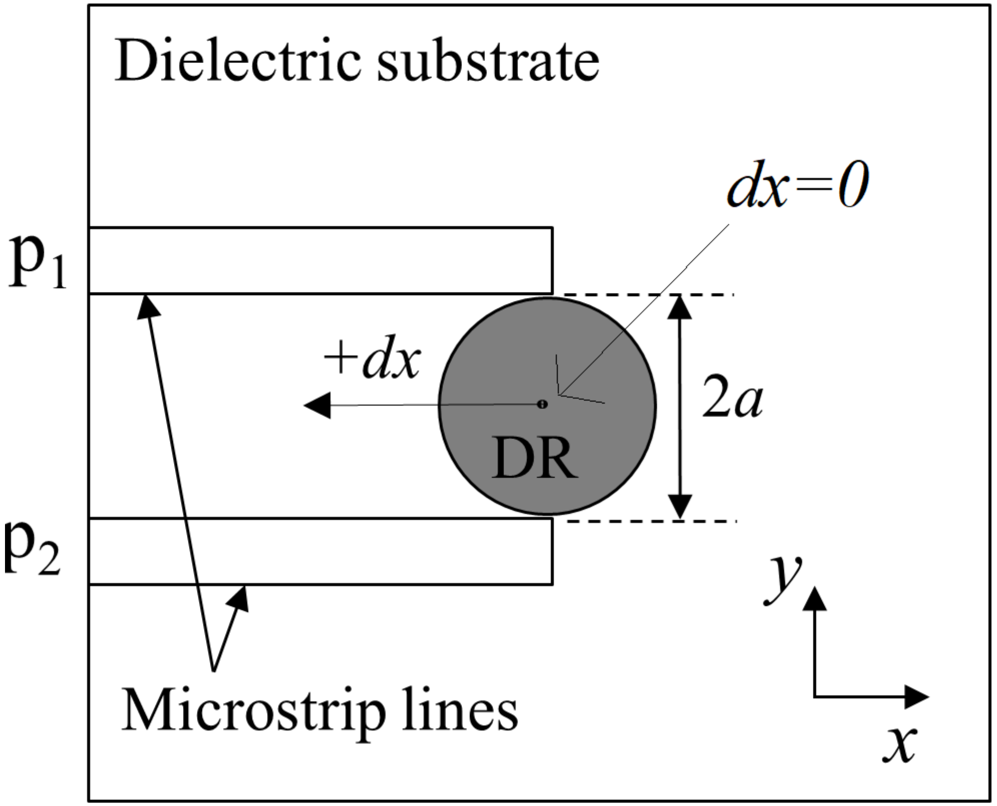


y_off = 10 cells



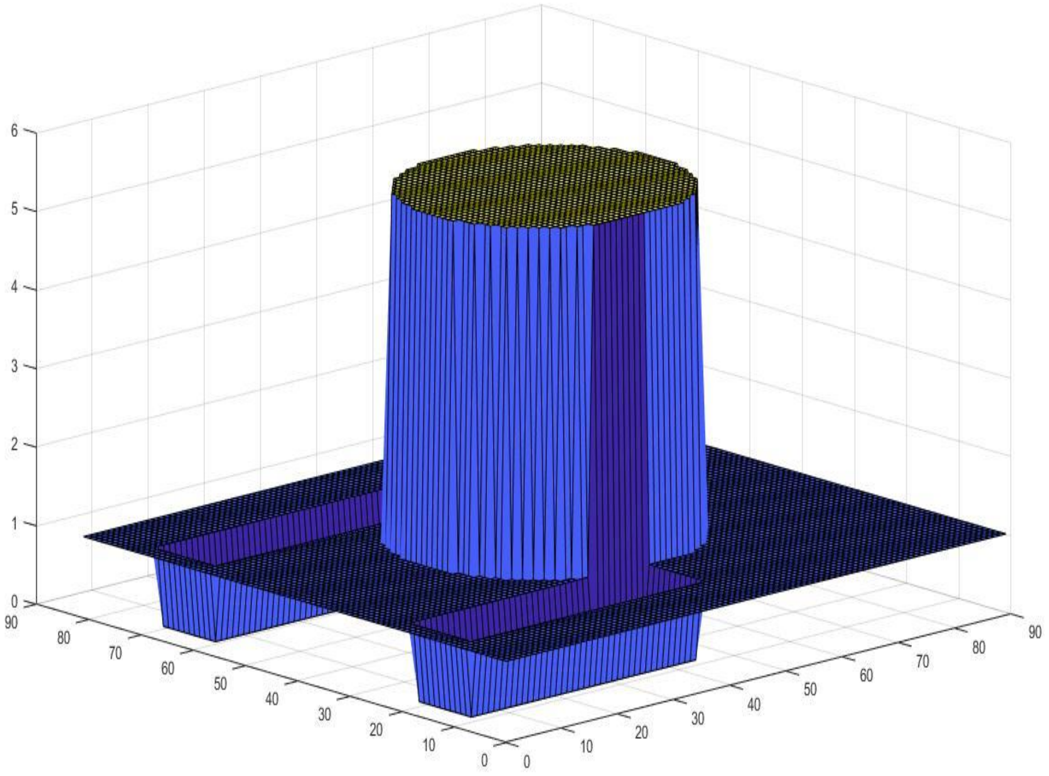
y_off = 20 cells

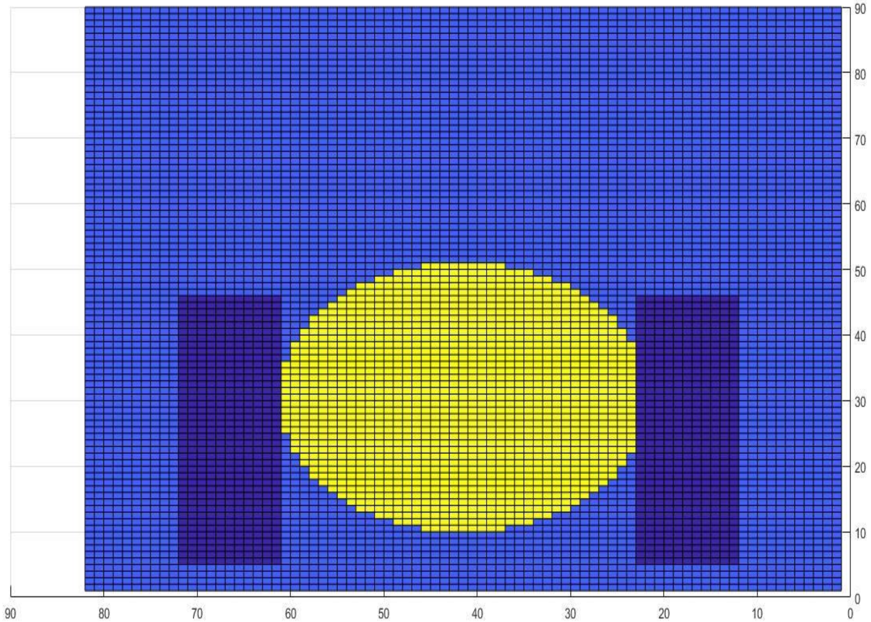
Final Structure -
Two striplines with cylindrical dielectric region



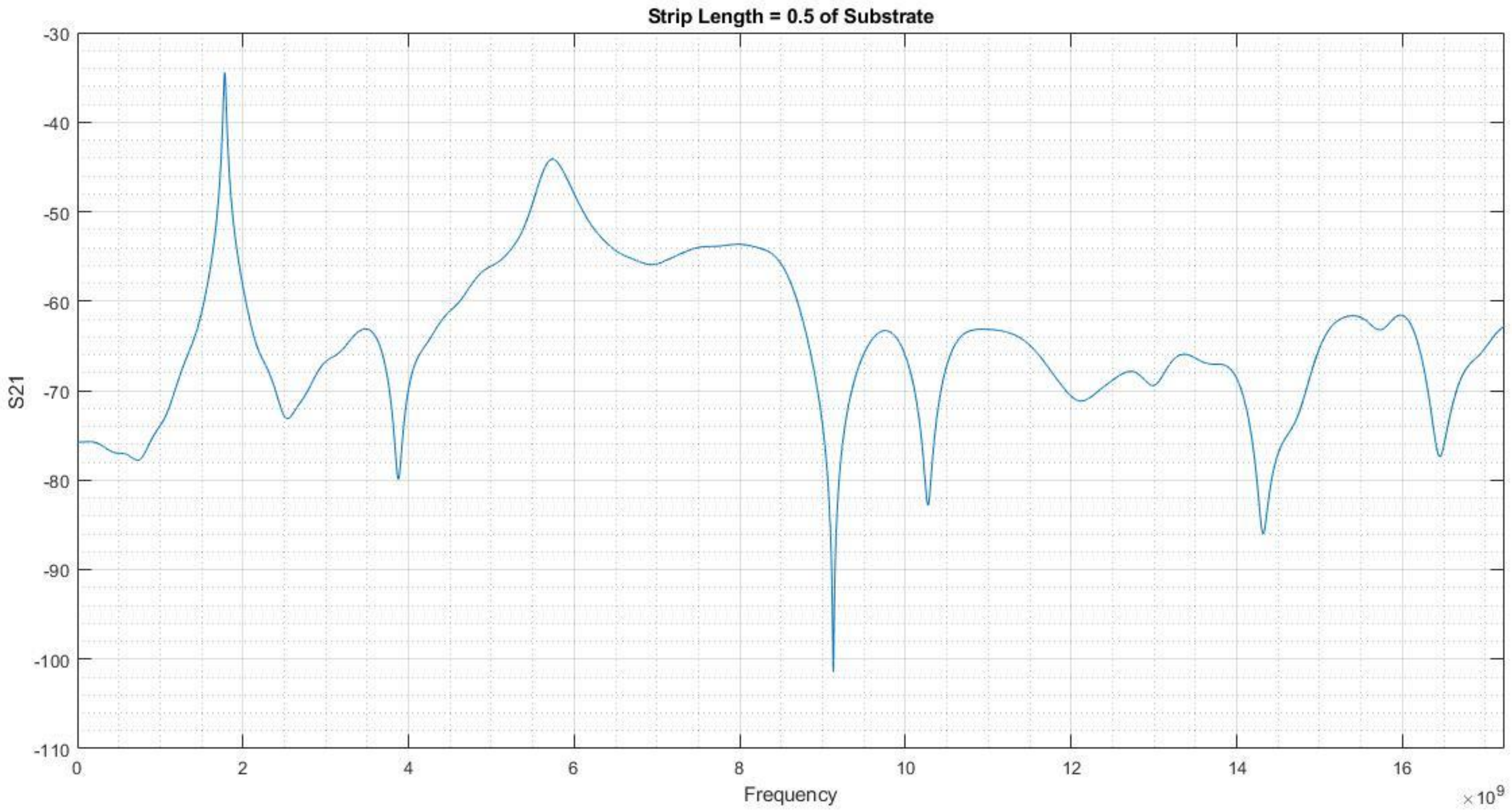
2a=19.43 mm
h=7.3 mm
epsr=24

gx Surface Plots

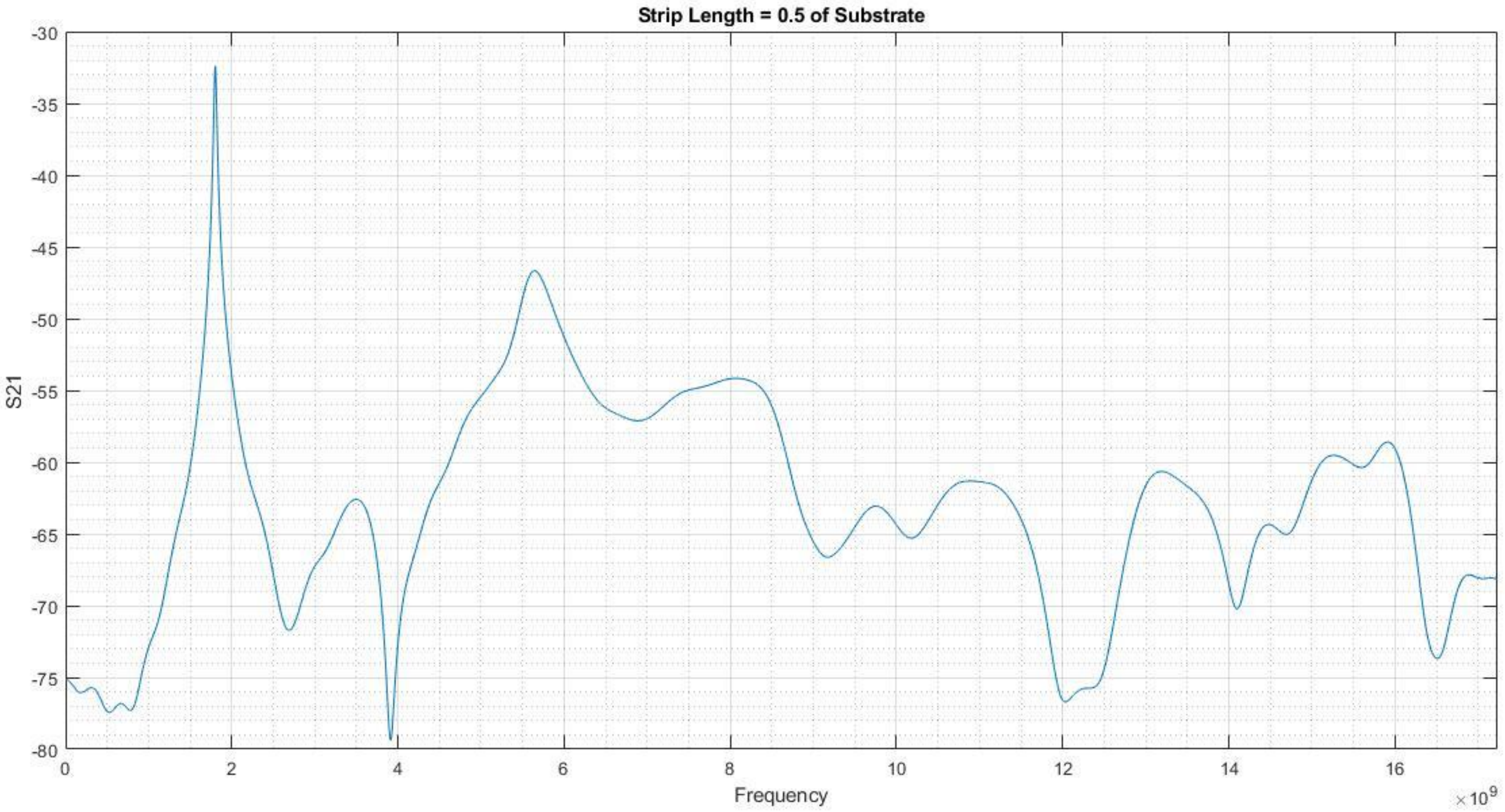




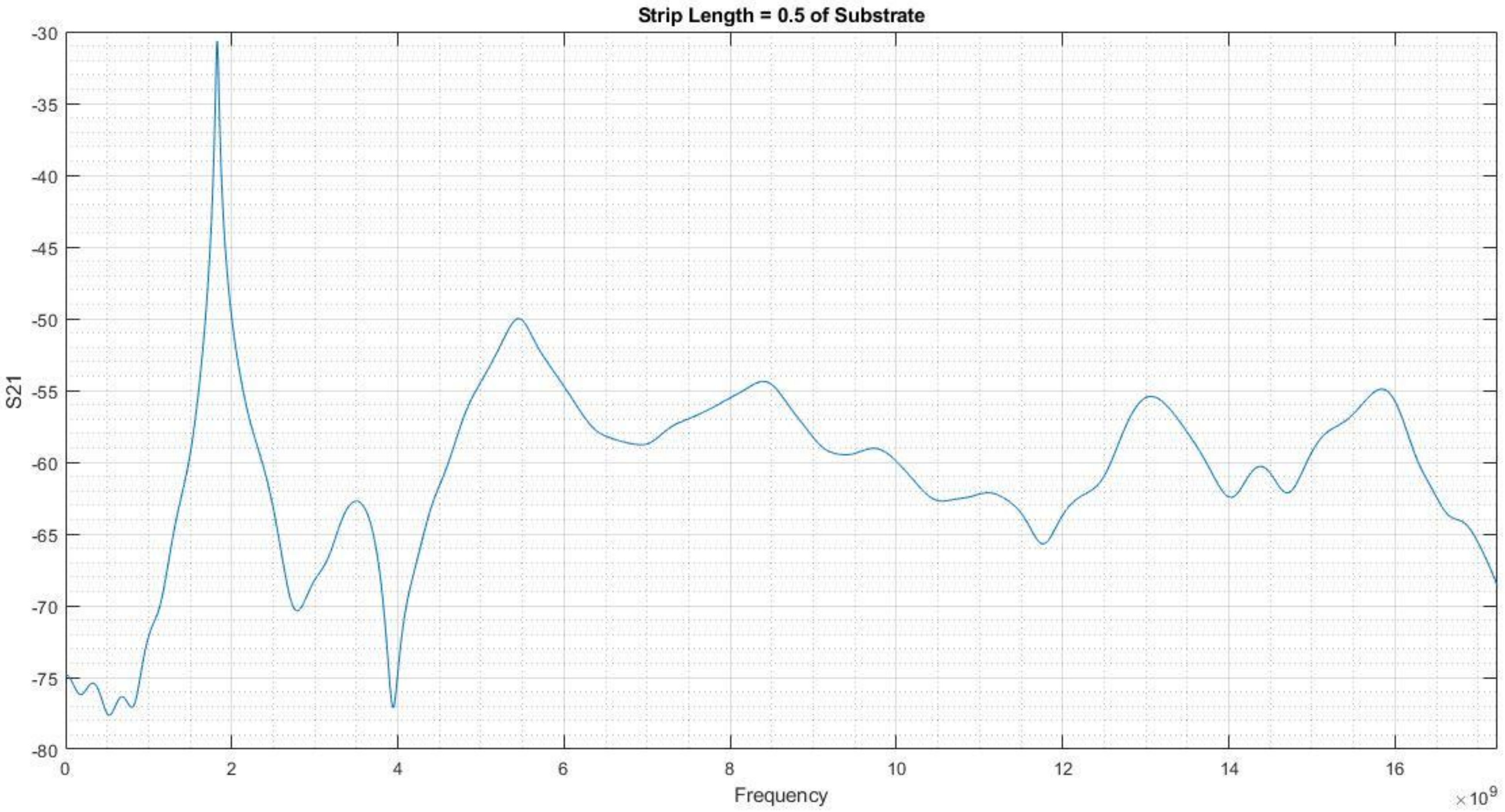
S_{21} plots change with variation in displacement (dx) of DR



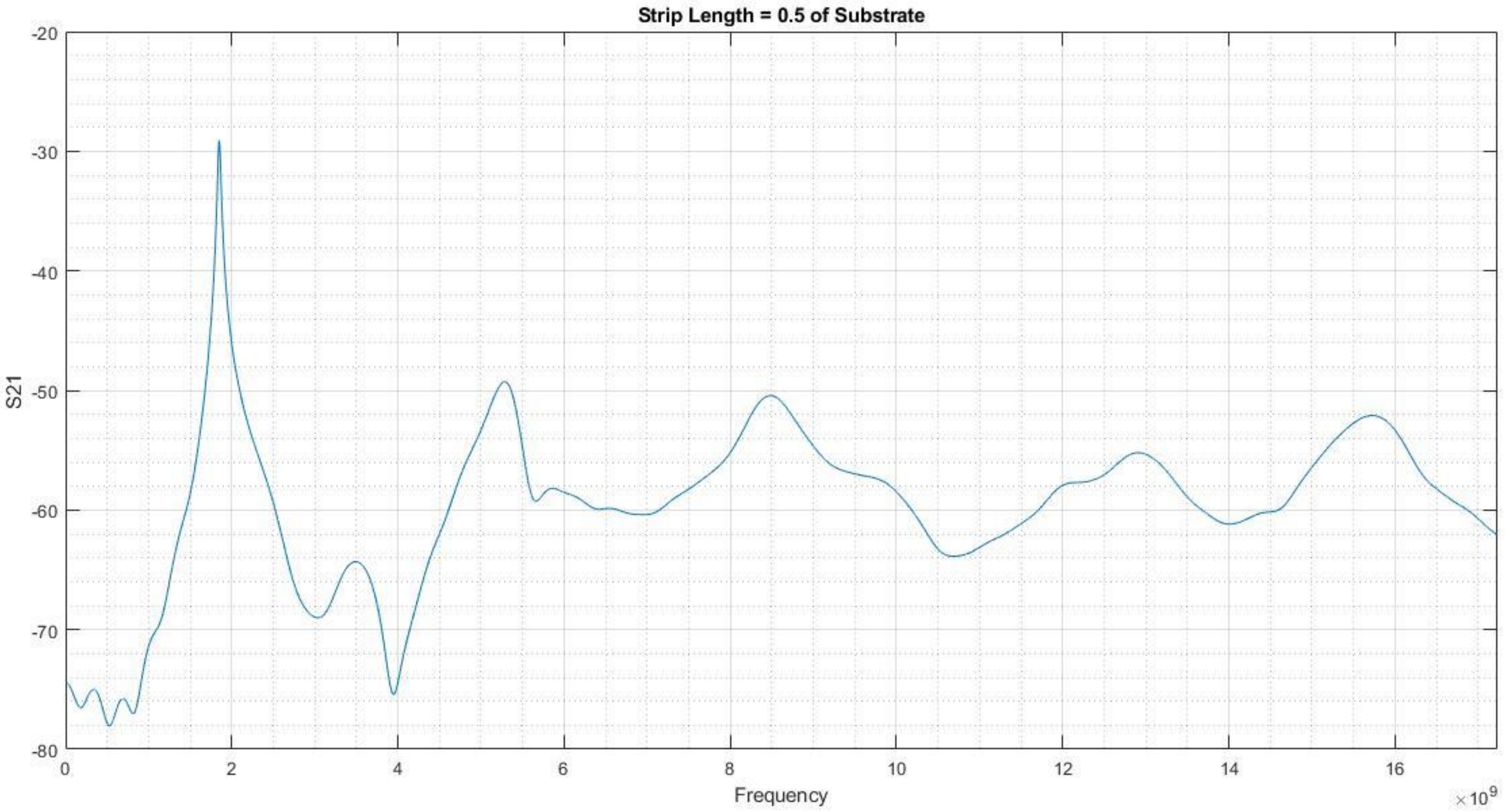
dx = 8 cells


Strip Length = 0.5 of Substrate
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
S21
0
2
4
6
8
10
12
14
16
Frequency
×10^9

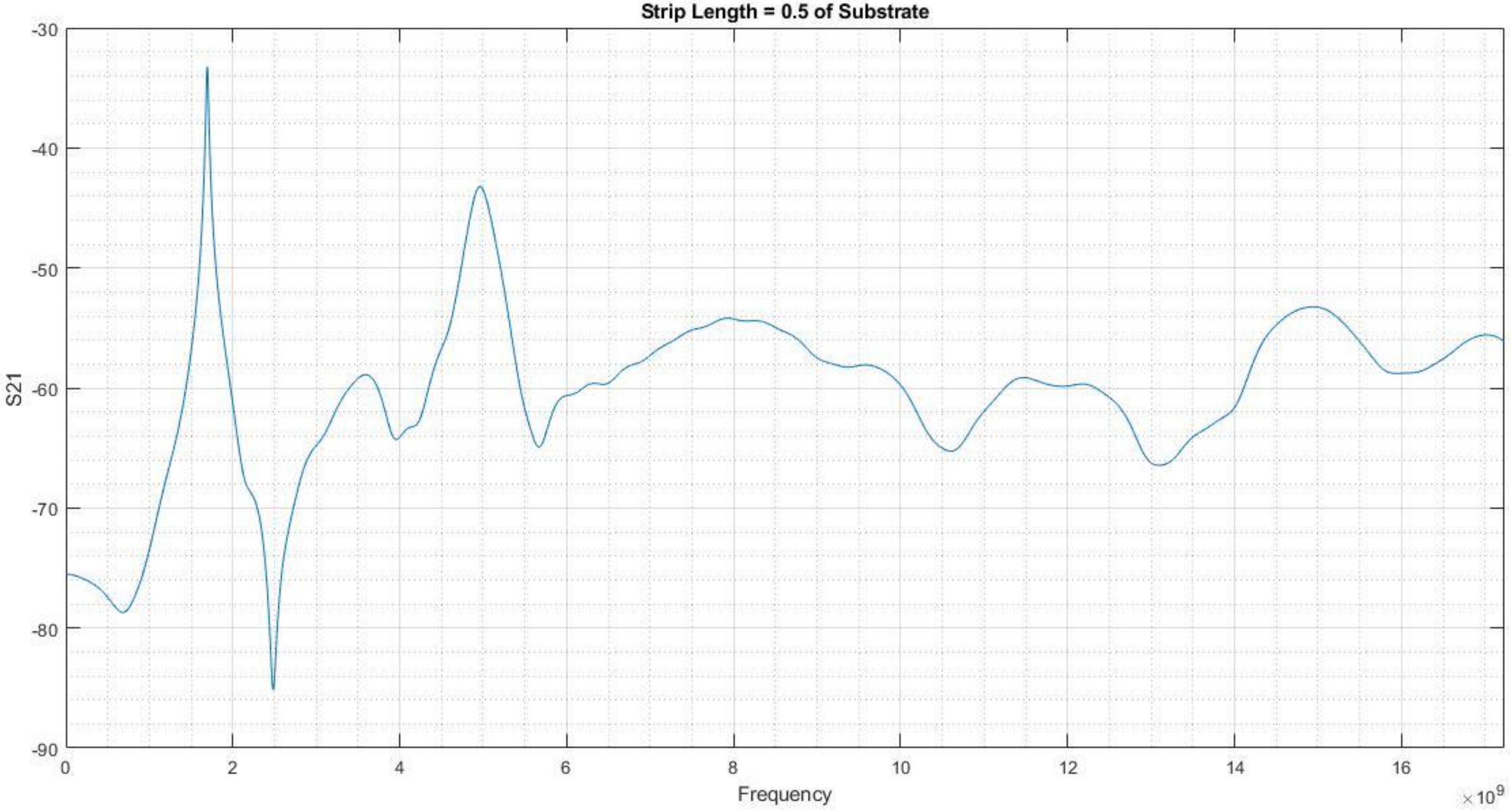
dx = 9 cells


Strip Length = 0.5 of Substrate
S21
Frequency
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
0
2
4
6
8
10
12
14
16
× 10^9

dx = 10 cells

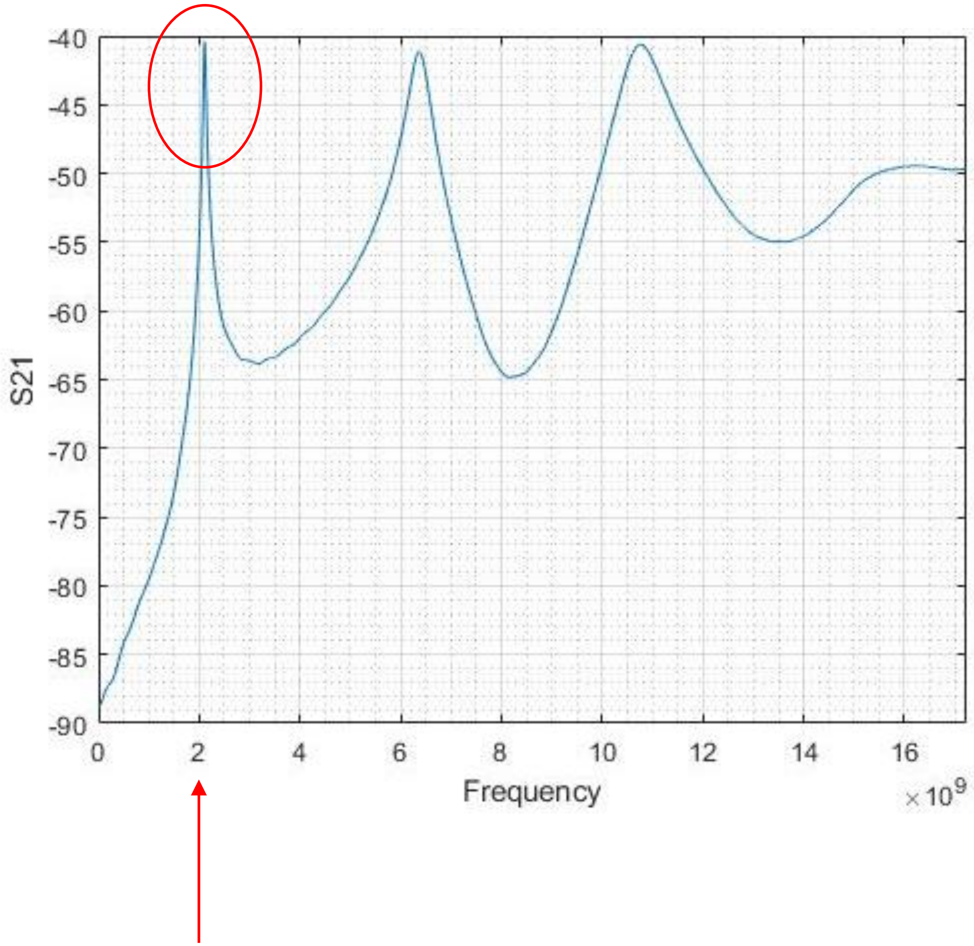

Strip Length = 0.5 of Substrate
-20
-30
-40
-50
-60
-70
-80
S21
0
2
4
6
8
10
12
14
16
Frequency
× 10^9

dx = 11 cells


Strip Length = 0.5 of Substrate
-30
-40
-50
-60
-70
-80
-90
S21
0
2
4
6
8
10
12
14
16
Frequency
×10^9

dx = 12 cells

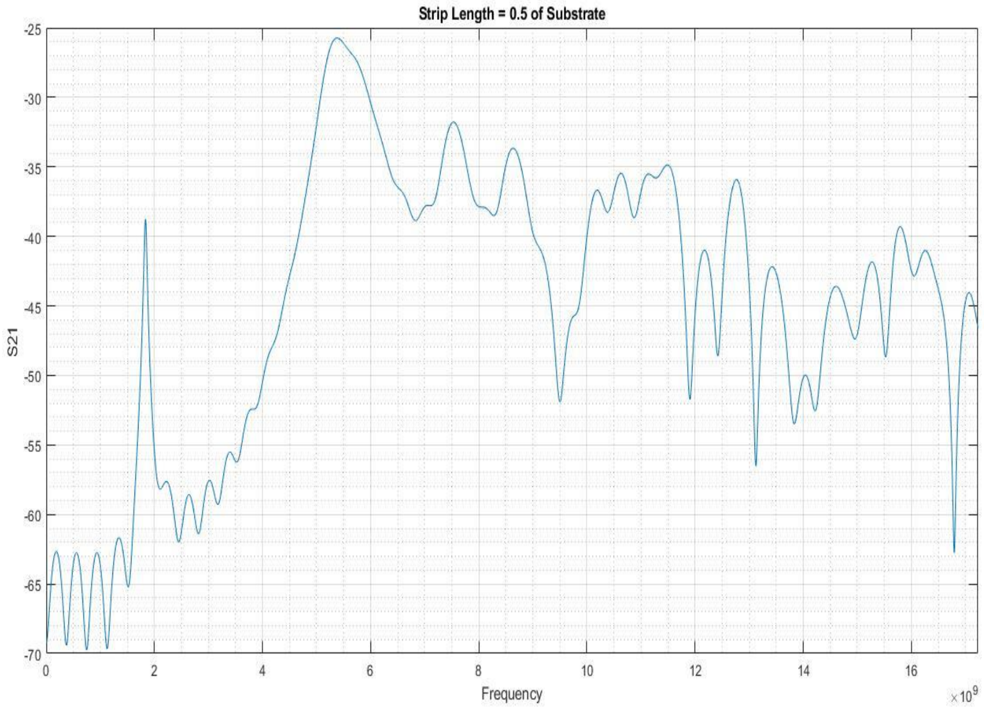
Observations



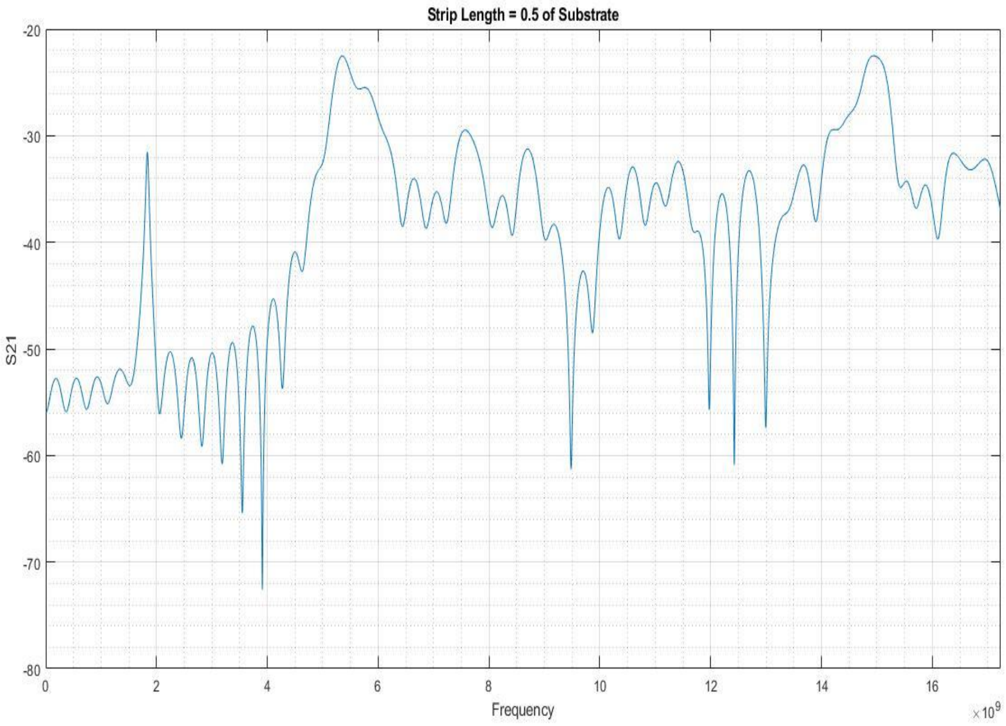
- There is a peak between -30 to -40 dB around 2 GHz in every case
- It is also present in the absence of DR
- The cause could be attributed to some numerical error, which needs to be investigated

S_{21} plots also change with variation in Air column height (y_off) above DR

Results for dx = 10 -



y_off = 20 cells



y_off = 10 cells

Thank You