Experiment 3

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Introduction

This assignment mainly deals with generating Electric fields of a laser with given linewidths and seeing their effect on phase noise and the effect of time duration it's run for.
The second part deals with plotting the PSDs of Electric fields with different linewidths and confirming the lorentzian fit for them and their respective linewidths.

Scatterplots of Electric Fields of different linewidths:

To obtain the electric field , we just pass the linewidth, average power and sampling frequency parameters to the 'LASER' function and receive an output with given phase noise and average power.

This field is then directly plotted using the 'scatterplot' function.
In Question 1,the sampling frequency used is 100 MHz for all cases . This is because if we want to observe the property of lasers with different linewidth for a given time, it only makes sense to have the same sampling frequency. Otherwise, the noise accumulated will now be a function of sampling frequency as well. Also, a minimum of 1000 points is needed, so we chose 100MHz sampling frequency corresponding to a time of 10us.

For Question 2, if we were to have atleast 1000 points, the distinction between the three cases will become less clear because the sampling frequency would be more, hence the same sampling frequency of 100MHz was used here as well.
The results and observations for various cases of time, linewidth are given below:

LW 1KHz:

Electric fields are plotted for a linewidth of 1KHz for 10us and 100us as shown in fig. 1 and 2.

LW 10KHz:

Electric fields are plotted for a linewidth of 10KHz for 10us and 100us as shown in fig. 3 and 4.

LW 100KHz:

Electric fields are plotted for a linewidth of 100KHz for 10us and 100us as shown in fig. 5 and 6.

We see that the deviation in phase of Electric field increases with time for all the cases. This is because phase noise a random walk process keeps accumulating with time. We also see that the deviation is more for a higher linewidth laser for a given time. This is because phase noise increases with the linewidth of the lorentzian PSD of the laser. The Electric field for a LW of 100KHz for 100us completes a full circle.

LW 1MHz:

We now repeat the same process for a linewidth of 1MHz. We use the same sampling frequency of 100MHz for three time durations: 1us, 10us, 100us. The plots for these times are as shown in fig. 7,8 and 9 respectively. The sampling frequency used here is the same as for the linewidths of 1KHz, 10KHz and 100KHz so that we can compare them with the 1MHz case without bias. We see that the phase noise increases as we increase the time as usual, but we also see that the phase noise covers the whole circle in 10us itself for a linewidth of 1MHz. This is obvious since the linewidth is much higher than the earlier cases. For 100us, the spread is over the whole circle but its more dense.

PSD plots for Electric fields of different linewidths:

Now, we plot the PSD for a laser source with three linewidths: 1 KHz, 10KHz and 1MHz. The field from the laser function is taken and given to the 'PSD plot' function where it estimates PSD from fft by taking it's absolute square. Since the Electric field a complex signal with phase noise the two sided PSD is computed.The PSD is then normalized for the fitting.
After this, in order to fit it to a lorentzian we use the curve fitting app and enter a custom equation corresponding to a lorentzian given by:

$$Normalized\ PSD = \frac{(fwhm/2)^2}{((f-fo)^2 + (fwhm/2)^2)} \tag{1}$$

where,
f is frequency
fo is the center frequency

fwhm is the full width at half maximum
We take a shifted lorentzian here, as it's noisy Electric field data and an estimate (via FFT) of it's PSD that we are calculating. Hence, we can tolerate small shifts in frequencies. The curve fitting done and presented here is the end of an iterative process after many re-runs and fits, hence we can't expect the same fit as presented here everytime the curve fitting is done in MATLAB.

1KHz:

We use total number of points (N lw1) and sampling frequency (fs lw1) instead of using time duration and sampling frequency independently, so that we can change the total number of points directly and the time duration keeps getting adjusted which is convenient for curve fitting. The chosen values are:

No. of points: 1400
Sampling freq. : $600*10^3$ Hz
Time duration: 2.33ms

We take only 1400 points because as the number of points increase the plot becomes more noisy and crowded with points and the curve fitting becomes harder and too low points wouldn't give a lot of points near f=0. The sampling frequency is chosen as 600KHz because the number of points near f=0 or under the FWHM are very low. If we were to lower the sampling frequency considerably (near 2-3 KHz lets say), then the fit doesn't turn out to be accurate (since fs limits the seen frequency range). Intuitively, this may be because for a lorentzian, we need the data to explicitly show the decaying parts. Higher sampling frequencies aren't used because the no. of points near f=0 or under the fwhm decreases. Additionally, it satisfies nyquist criterion to a good extent. The time duration is just a division of total points and sampling frequency.
The curve fitting GUI window and the resulting predicted 'fo' (center frequency) and 'fwhm' for the 1KHz case are shown in fig. 10. Additionally, the actual fit and the original plot of normalized PSD is shown in fig. 11. It's seen that the FWHM found is around 1.123KHz with a center offset of around 160Hz, which is close to the theoretical value.

10KHz:

The chosen values are:

No. of points: 60
Sampling freq. :$300*10^3$ Hz
Time duration: 200us

The total points are only 60 so that we cover many points near the FWHM region and the FWHM is higher in this case as well which is why we can afford this. The sampling frequency is 300 KHz which is just 30 times FWHM, relatively smaller compared to earlier because again higher sampling frequency would prevent generation of points in the FWHM region and this 'fs' is enough to also represent the decaying part of the lorentzian. This also satisfies nyquist criterion to a good extent.

The FWHM predicted is seen to be around 10.21KHz with a center offset of around 500Hz as seen in fig. 12. The actual PSD plot and it's fit is seen in fig.13.

1MHz:

For this linewidth, the Electric field is averaged over many iterations and the PSD is smoothened out for curve fitting because there may be a lot of noise considering a higher frequency range (in MHz).
The chosen values are:

No. of points: 200
Sampling freq. : $3*10^6$Hz
Time duration: 66.67us

In this case, the FWHM is in MHz, so we need to take lower points and a lower frequency window as well, because if we have a larger frequency window of the order of MHz, theres a higher frequncy variation causing more PSD variation. So, higher number of points would give more noise making the curve fitting harder. Hence, it's found that these many points (or atleast number points of this order) are enough to describe the behaviour for this frequency window. The sampling frequency is chosen as 3MHz becuase firstly it satisfies nyquist to a good extent (the average psd values found at the edges are considerably low) and we can't go lower than this. A higher f-sampling isn't chosen because as usual we would lower the number of data

points near the peak (this would be more important for an FWHM window of 1MHz) and we see that the decaying nature of the data points for the lorentzian fit is taken into account at this sampling frequency.
The FWHM predicted as per the fit is around 0.84MHz with a center offset of around 20KHz as shown in fig. 14 which is close to the true value. The actual PSD and its lorentzian fit is shown in fig. 15.

In all three cases, the FWHM is verified even in the graphs for the actual PSD and it's fit.

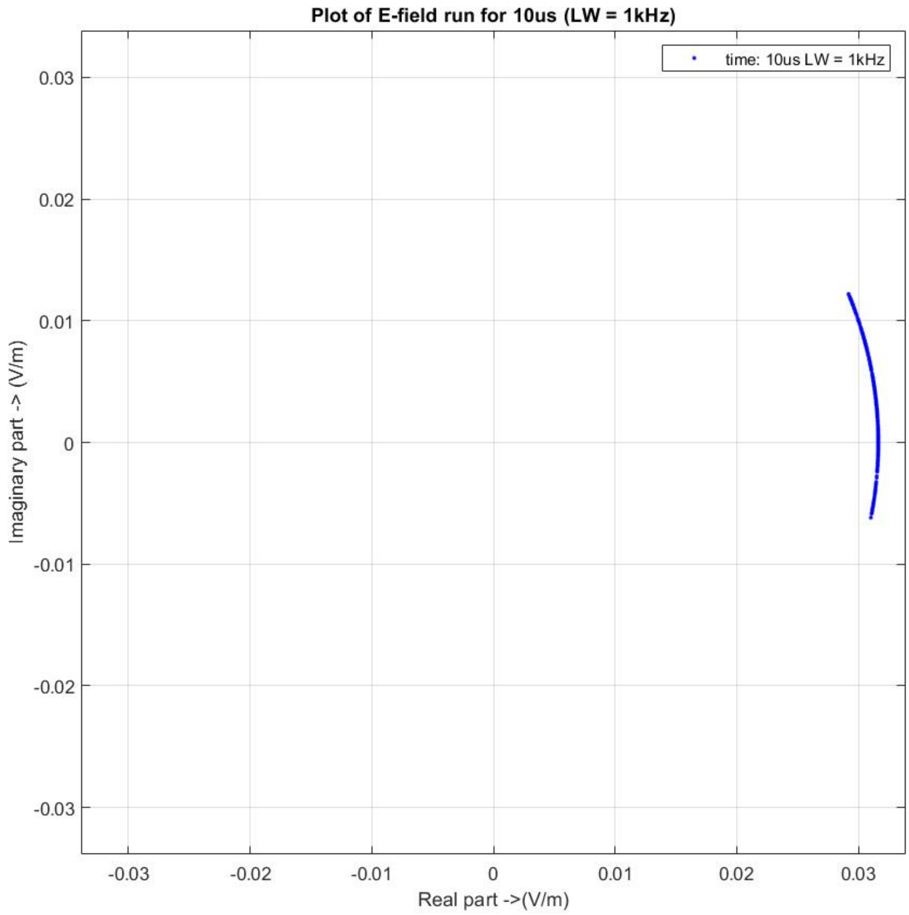

Figure 1: Plot of E-field for 10us (LW 1KHz).

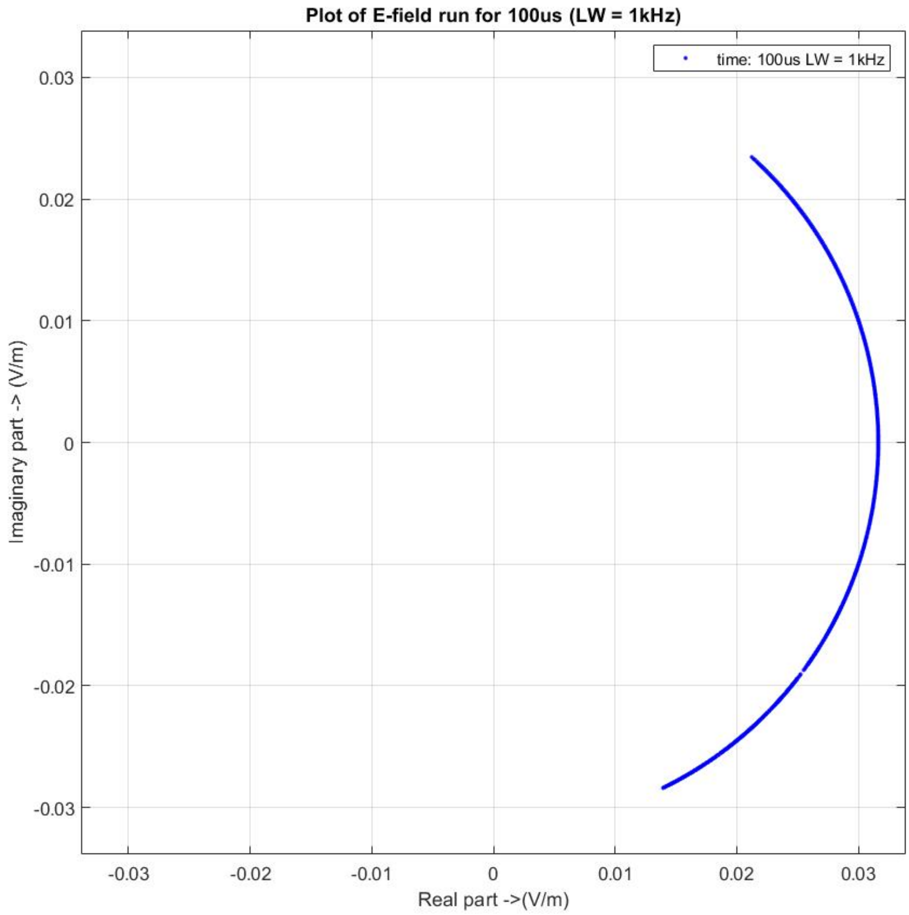

Figure 2: Plot of E-field for 100us (LW 1KHz).

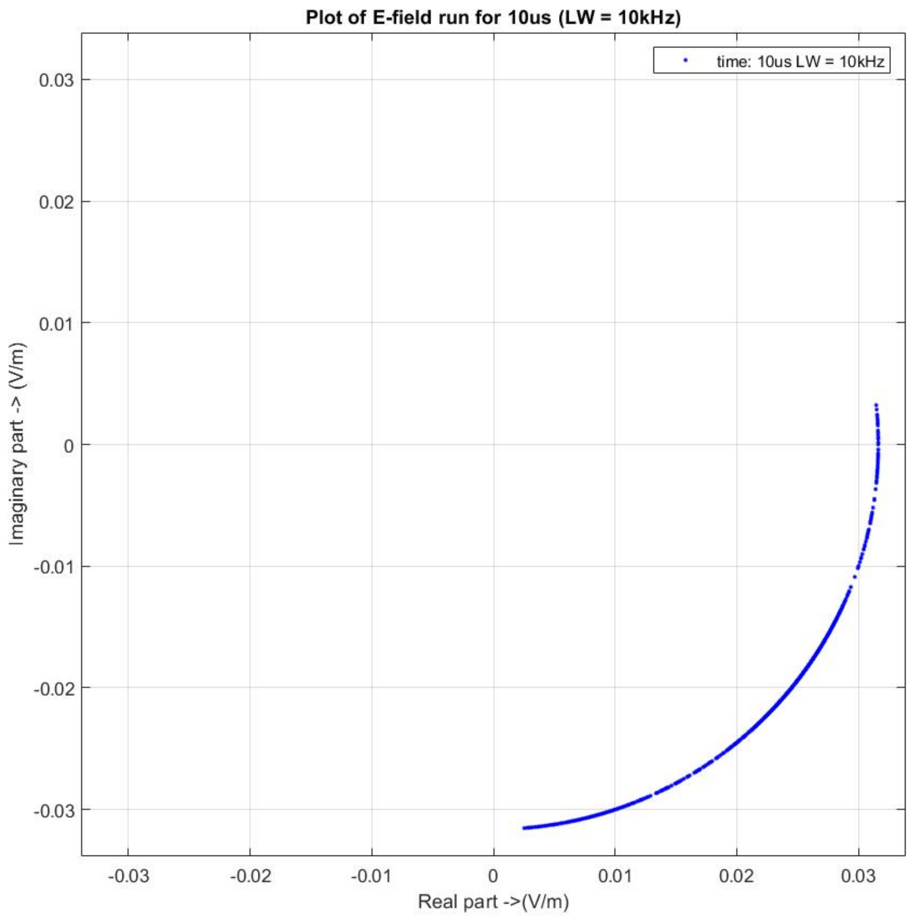

Figure 3: Plot of E-field for 10us (LW 10KHz).

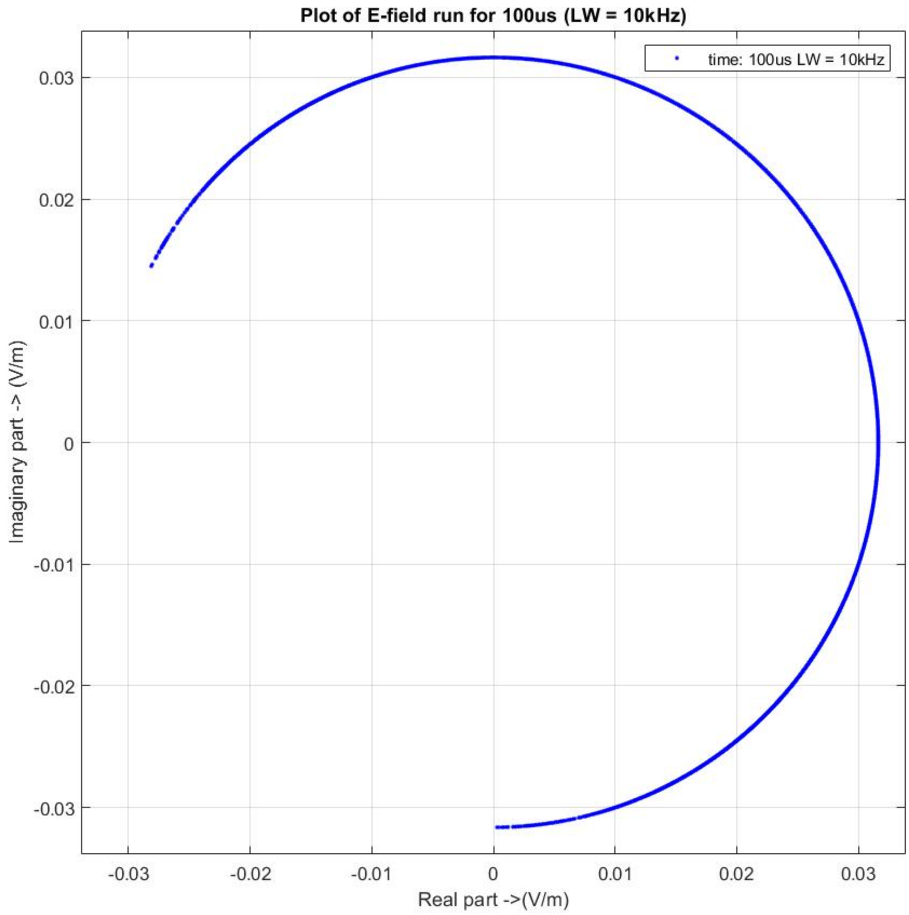

Figure 4: Plot of E-field for 100us (LW 10KHz).

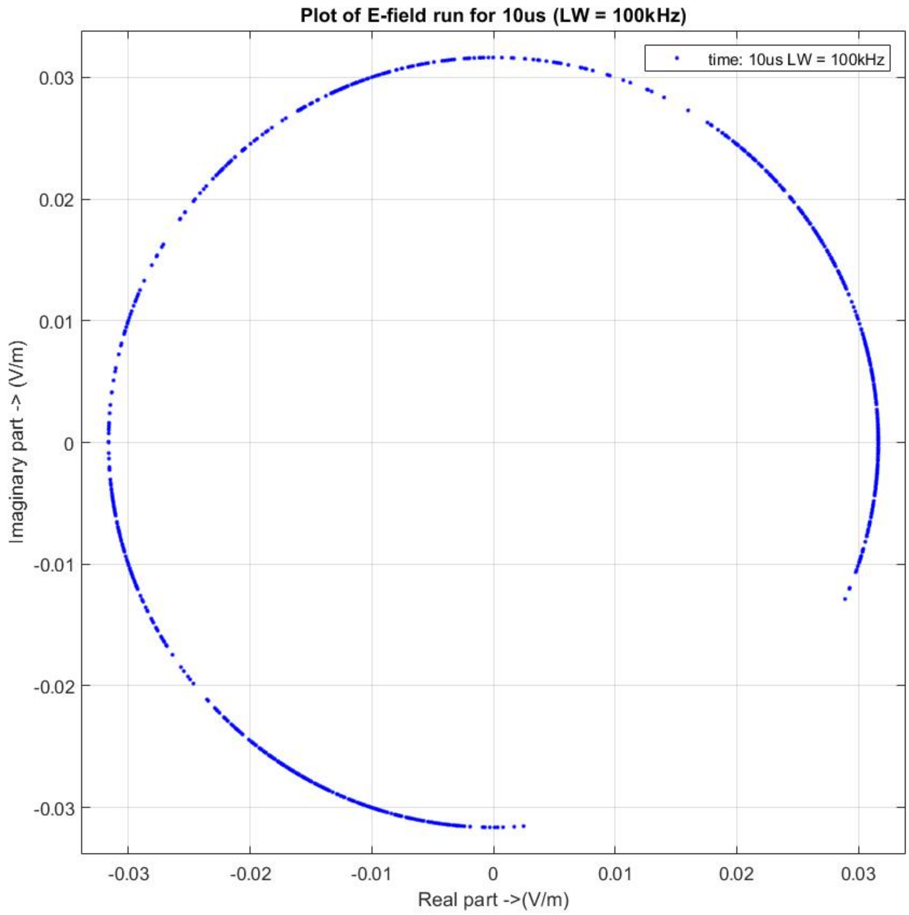

Figure 5: Plot of E-field for 10us (LW 100KHz).

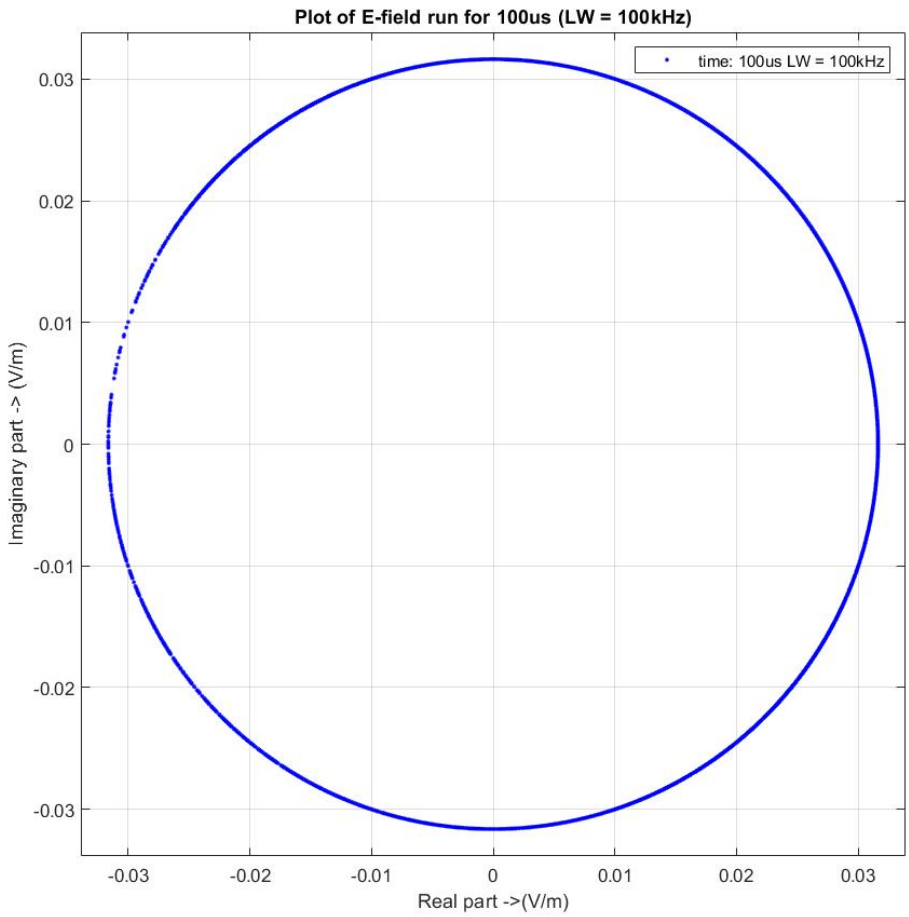

Figure 6: Plot of E-field for 100us (LW 100KHz).

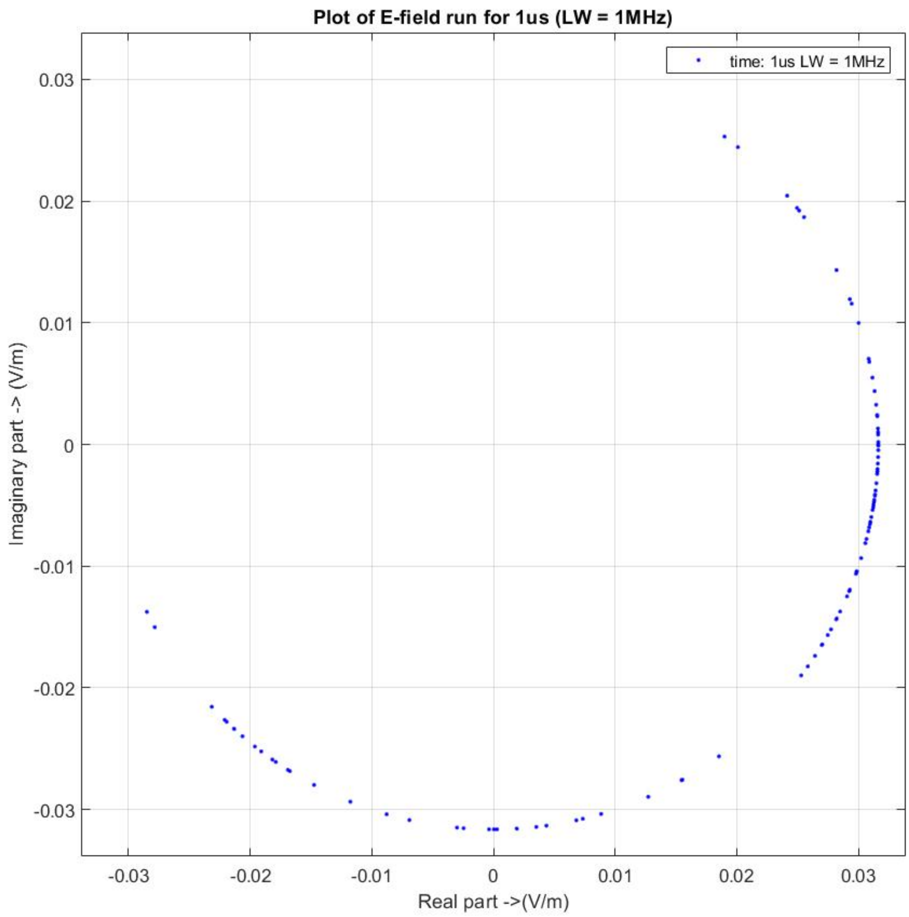

Figure 7: Plot of E-field for 1us (LW 1MHz).

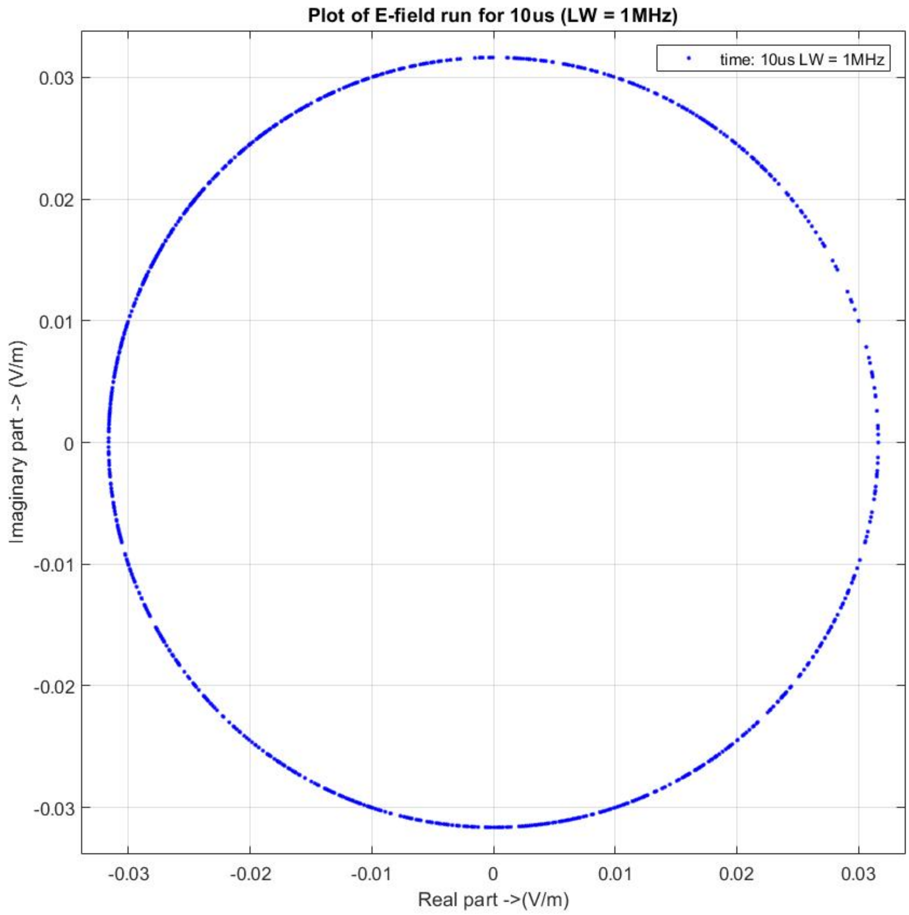

Figure 8: Plot of E-field for 10us (LW 1MHz).

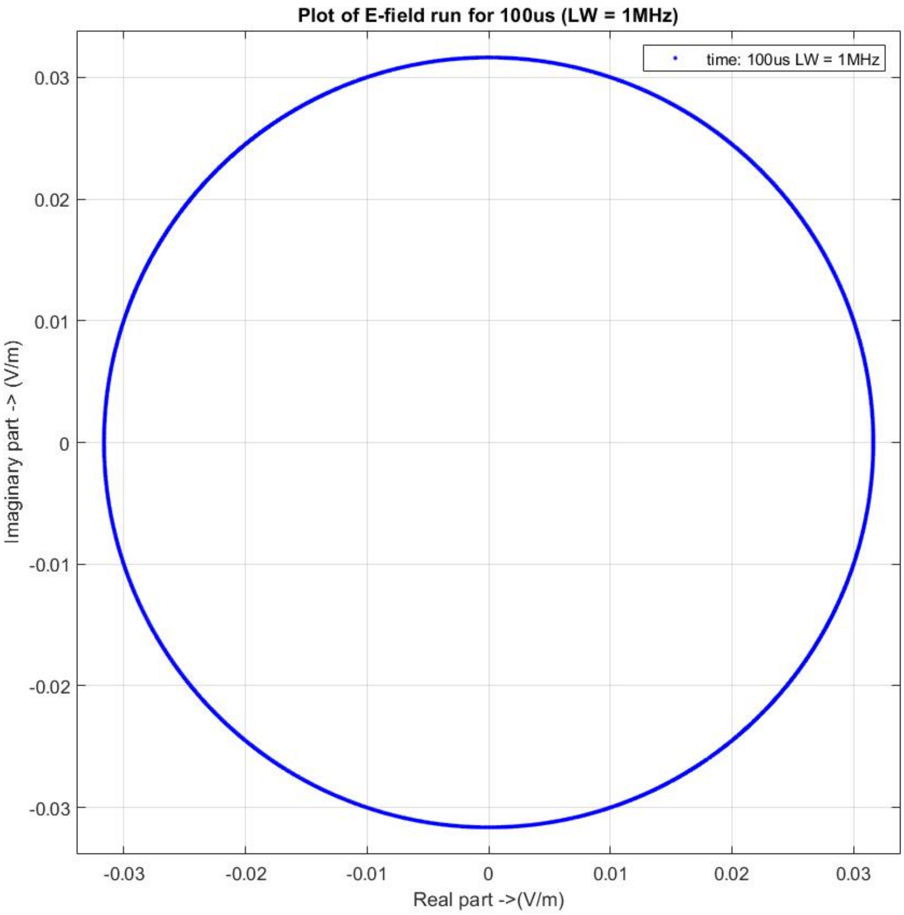

Figure 9: Plot of E-field for 100us (LW 1MHz).

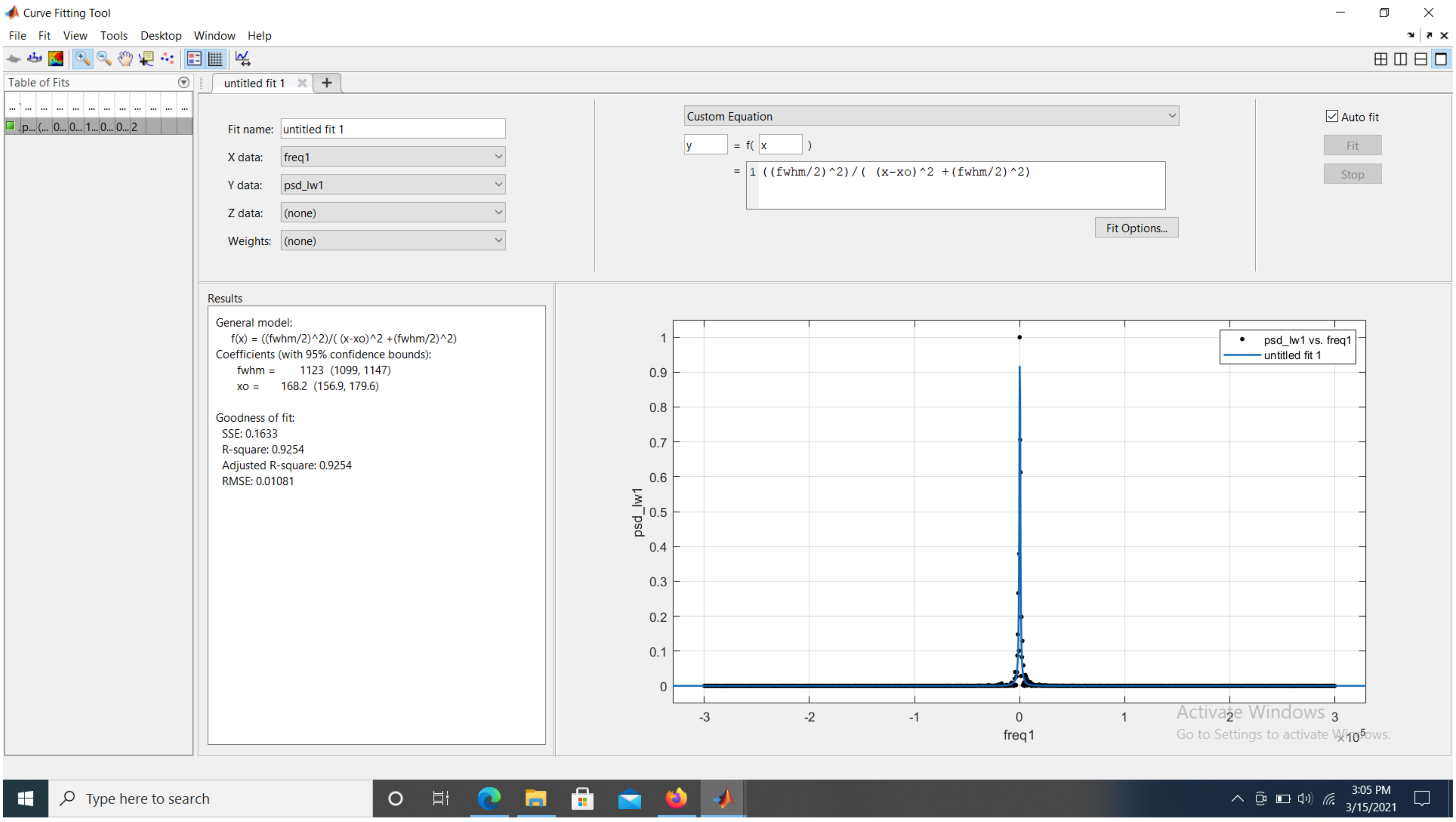

Figure 10: Curve fitting results for LW = 1KHz case.

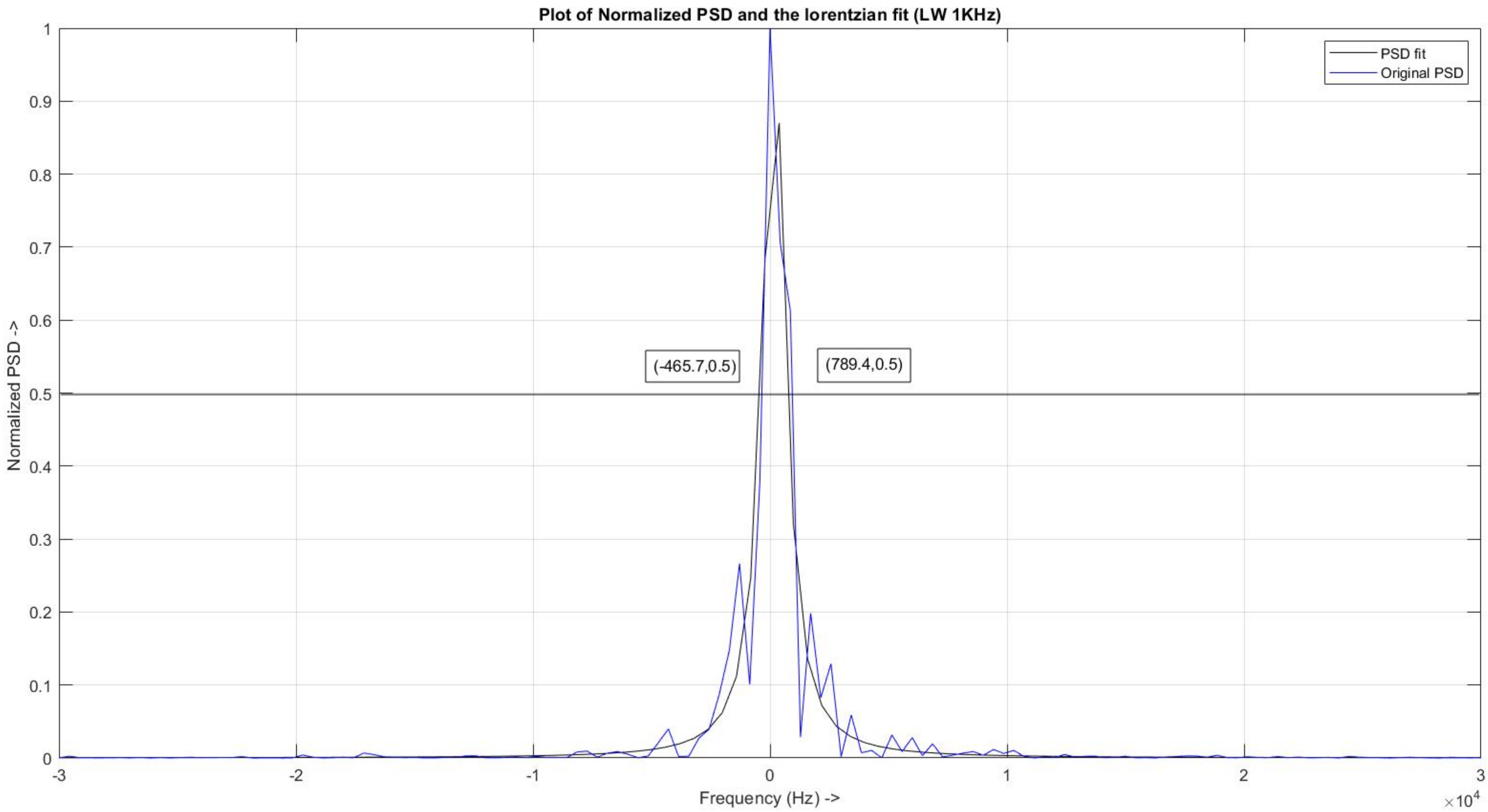

Figure 11: Normalized PSD- actual and lorentzian fit for LW= 1KHz case.

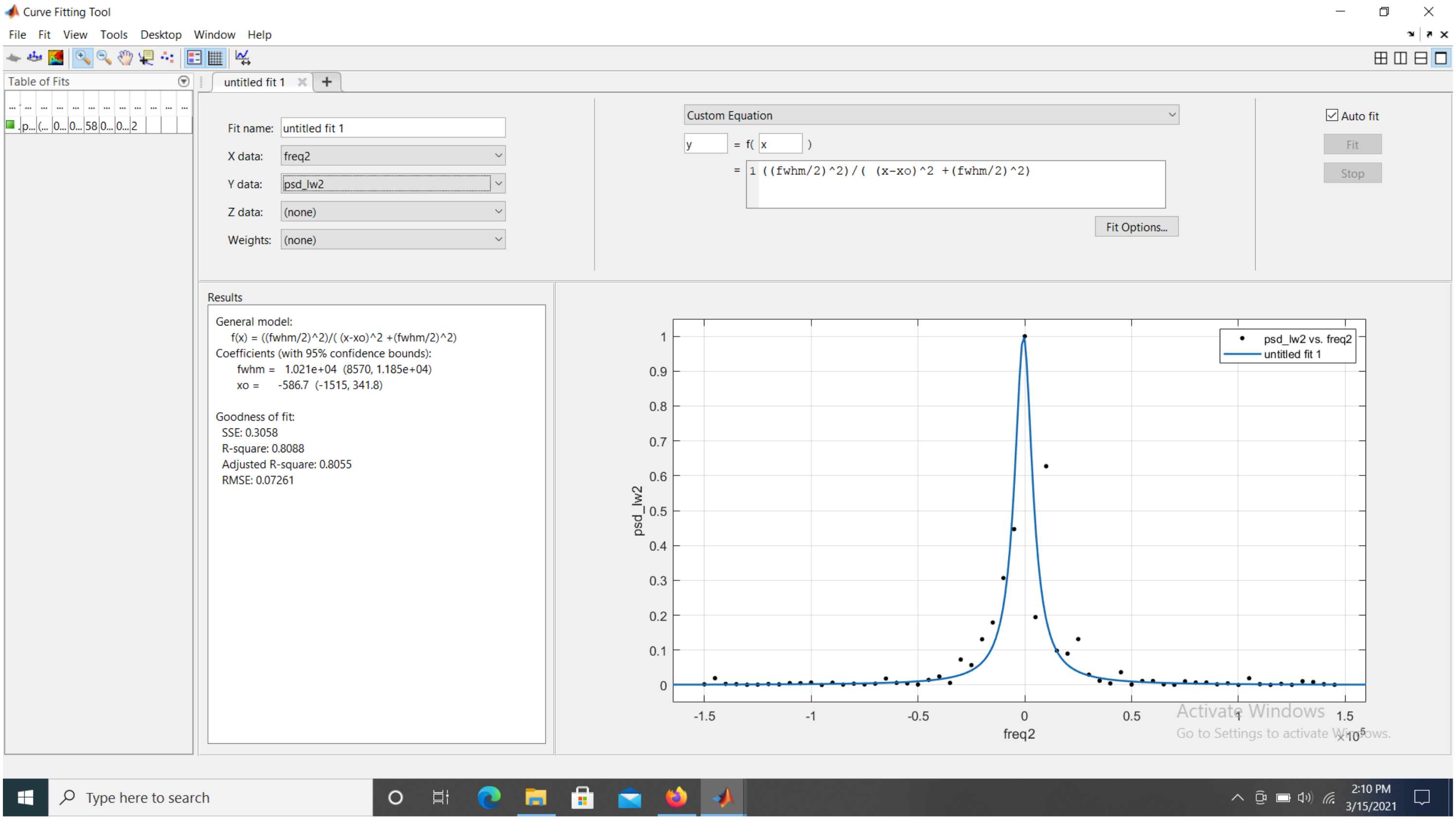

Figure 12: Curve fitting results for LW = 10KHz case.

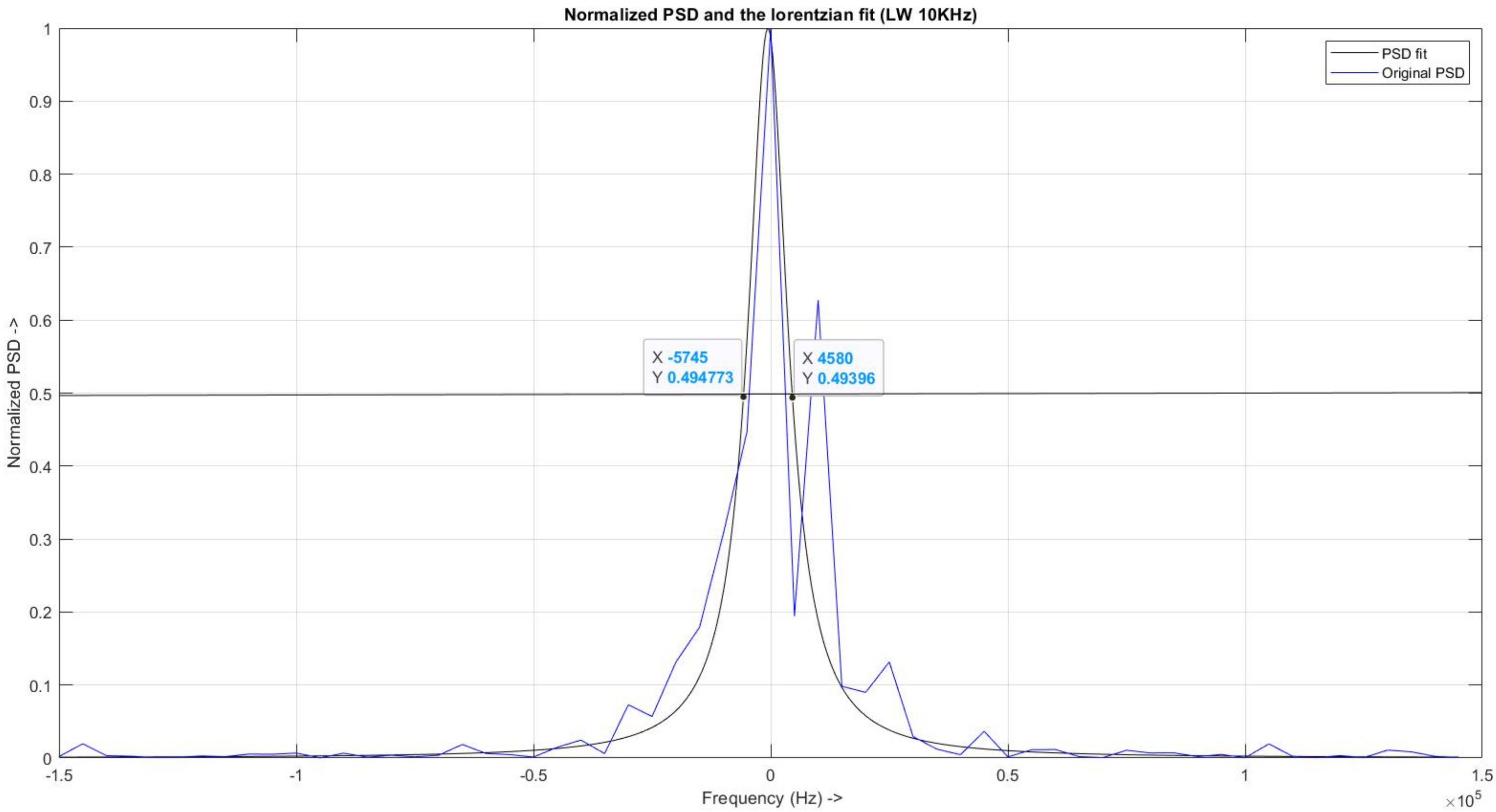

Figure 13: Normalized PSD- actual and lorentzian fit for LW= 10KHz case.

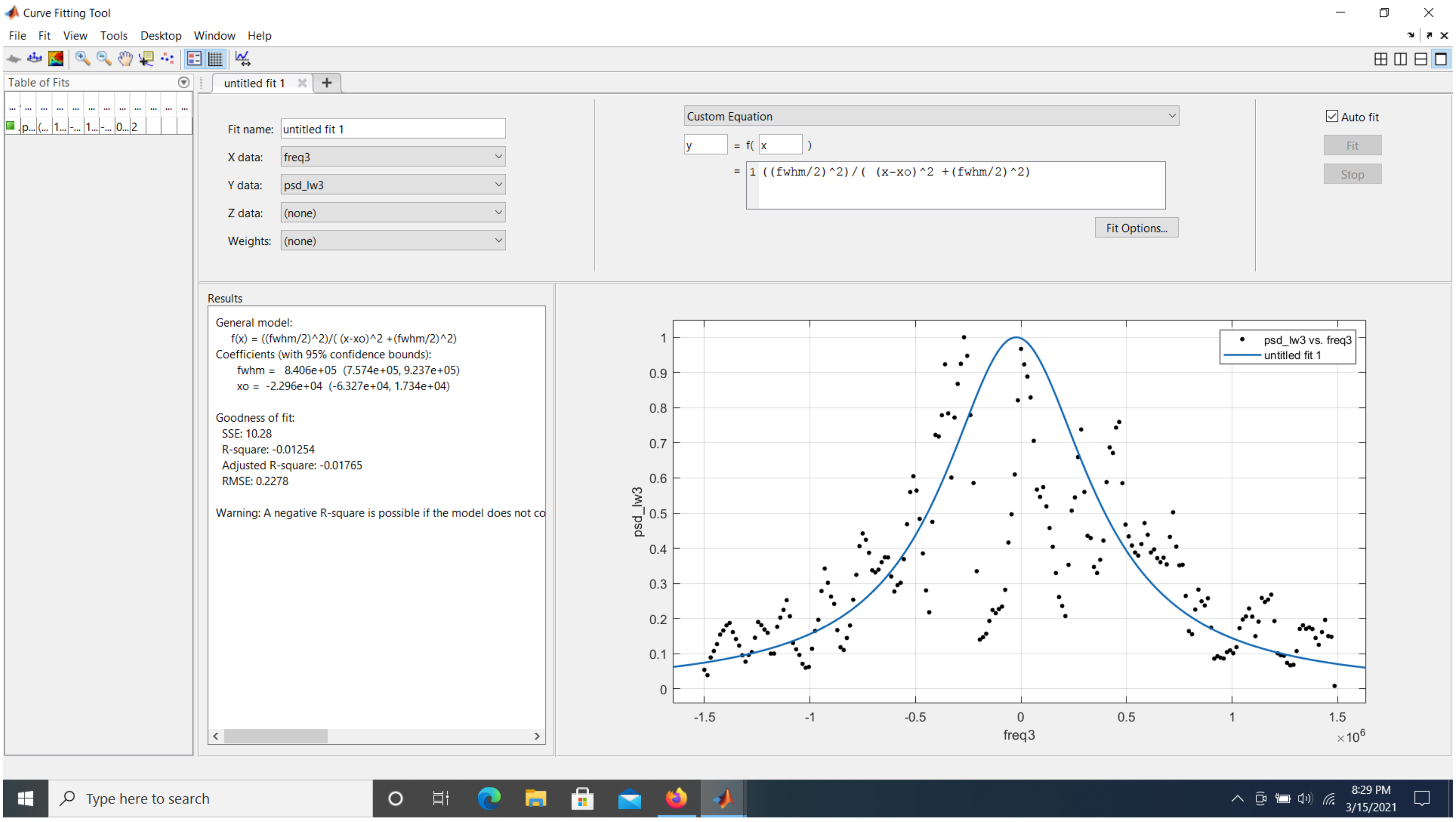

Figure 14: Curve fitting results for LW = 1MHz case.

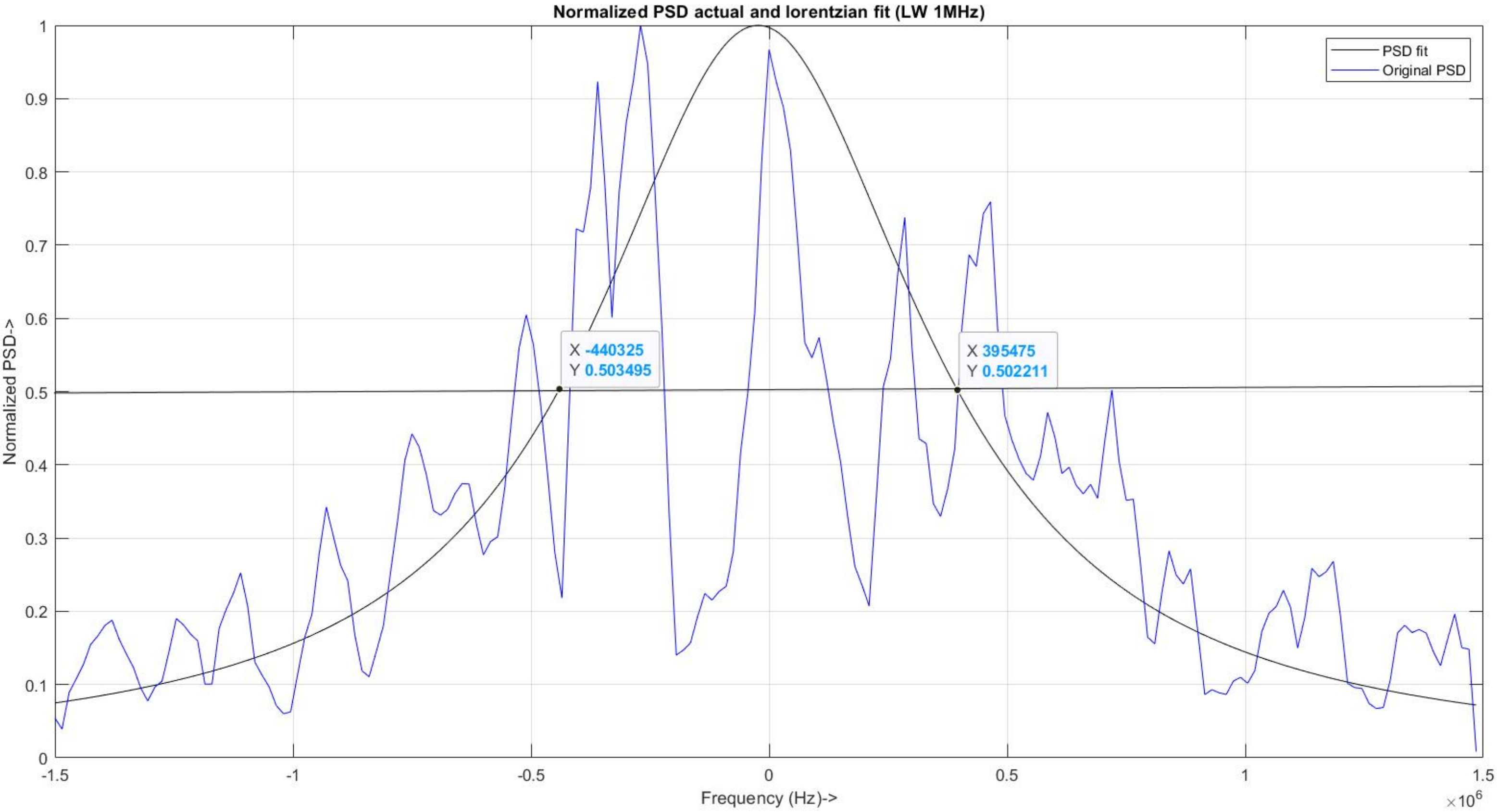

Figure 15: Normalized PSD- actual and lorentzian fit for LW= 1MHz case.