SSY135 – Wireless Communications MATLAB Project-1

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***Abstract*—The effectiveness of an OFDM communication system over a fading channel is assessed in this project. Additionally, we simulated and examined a number of this channel's features.**

I. Introduction

The objective of this project is to get a clear understanding of wireless channels including Rayleigh and Rician flat fading channels using both spectrum and filter methods and their corresponding advantages and disadvantages. Here we simulate both channels with Clarke's Doppler spectrum and analyze the quality of fading with respect to auto-correlation and power spectral density(PSD). We also discuss the methods to generate a time and frequency-varying channel response and analyze the effect of delay spread and Doppler spread on a variation on time and frequency-varying channel.

II. Rayleigh and Rician Flat Fading Channels

Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices.
Rician fading is a stochastic model for radio propagation caused by the partial cancellation of a radio signal by itself. The signal arrives at the receiver by many different paths and hence exhibits multi-path interference, and at least one of the path is changing. Rician fading occurs when one of the paths, typically a line of sight signal or some strong reflection signals, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution.
In this part, we generate and simulate Rayleigh flat fading channel at a carrier frequency of 2 GHz, a transmitter-receiver relative speed 30 km/h and sample interval Ts = 0.1 ms for both filter and spectrum methods. We also generate and simulate Rician flat fading channel setting $c(nT_s) = c_{Rayleigh}(nTs) + k_c$ where $k_c \geq 0$ and is again normalized such that $\mathbb{E}(|c(nT_s)|^2) = 1$.

A. Determine largest possible value of T_s

Doppler frequency is calculated using the equation:

$$f_D = \frac{v \times f_c}{c} \approx 55.5Hz$$

In order to avoid any aliasing, choose T_s that satisfies the condition $1/T_s > 2f_D$ such $T_s < 9ms$. Since the provided value $T_s = 0.1ms$ satisfies the condition, thus it meets the requirement.

B. Estimation of power spectral density(PSD) of $c(nT_s)$ in MATLAB and comparison with theoretical

The figure shows the theoretical PSD v/s the estimated PSD of the simulated channels. For frequencies lower than Doppler frequency, the power is slightly more in both of the simulated channels compared to the theoretical one even though the curves are matching. It can be observed that in both methods large variance is present due to the presence of noise, which is found absent in the theoretical curve. The Doppler frequency, the spectrum and filter method differ by around 10dB whereas the theoretical is almost zero. Since the spectrum method has a steeper angle in cutting of the higher frequencies, it is comparatively better at suppressing higher frequencies.[Figure 1, 2]

C. Relation of k_c with Rician K-factor

Rician K-factor is defined as the ratio of signal power in the dominant component over the other multi-path component.

$$K = \frac{s^2}{2\sigma^2}$$

k_c is the power of the line of sight(LOS) component. While generating Rician channel it is normalized in order for the channel to be of unit energy $\mathbb{E}(|c(nT_s)|^2) = 1$. The K-factor is proportional to k_c. When $k_c = 0$, Rician channel is equal to the Rayleigh channel.

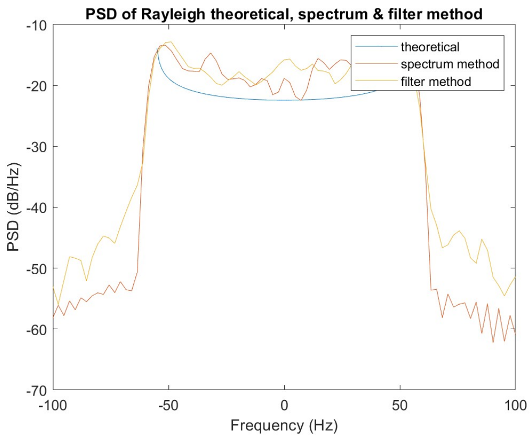


Fig. 1. PSD of Rayleigh fading channel

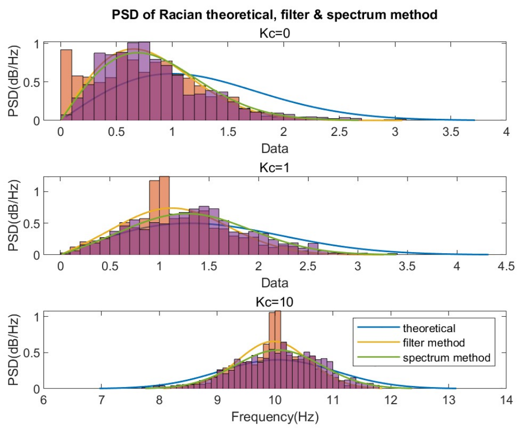


Fig. 2. PSD of Rician fading channel

D. Probability density function(PDF) comparison w.r.t k_c

In this section, we compare theoretical and estimated Rician PDF with respect to 3 different values of k_c. At $k_c = 0$, it can be observed that the PDF looks like a Rayleigh distribution centered around 0.75 because the LOS component is not present. At $k_c = 1$, the PDF shifts its center slightly but still, it looks similar to a Rayleigh distribution since only 1 LOS component is present and it didn't create much significant change in the PDF. However, at $k_c = 10$, we can observe a significant change in the PDF such that PDF distribution changes to a Gaussian distribution centered around its LOS value 10 and this is caused because the LOS components dominate over the non-LOS components. For all the values of k_c, it can be also seen that both the filter and spectrum methods provide an almost narrow curve with respect to the theoretical one which is due to the normalization of the channel in order to achieve unit variance.[Figure 3]

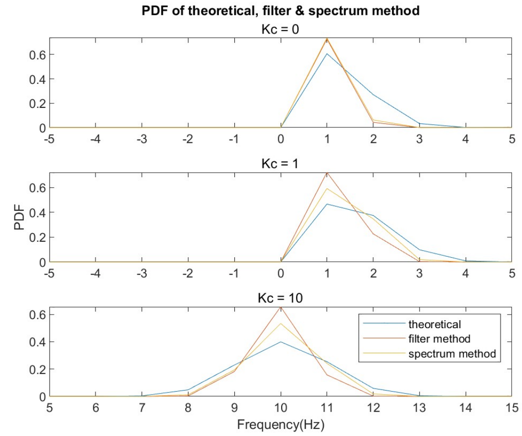


Fig. 3. PDF comparison w.r.t k_c

E. Cummulative density function(CDF) comparison w.r.t k_c

In this section, we compare theoretical and estimated Rician CDF with respect to 3 different values of k_c. At $k_c = 0$, it can be observed that the CDF of Rician looks similar to that of Rayleigh CDF. At $k_c = 1$, the CDF shifted slightly towards the right but as the value is increased to $k_c = 10$, we can observe a large shift of the CDF towards the right such the it gets centered around 10. This shows that k_c has a significant impact on the CDF. This shift in CDF with respect to k_c is due to the increase in SNR.[Figure 4]

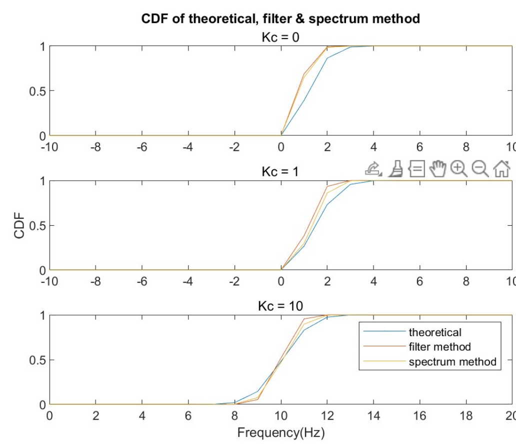


Fig. 4. CDF comparison w.r.t k_c

F. Auto-correlation function(ACF) comparison w.r.t k_c

The auto-correlation function of a signal is defined as the measure of similarity or coherence between a signal and its time-delayed version. Thus, auto-correlation is the correlation of a signal with itself. It is also known as serial correlation in the discrete-time case, which is the correlation of a signal with a delayed copy of itself as a function of delay. It is the similarity between observations of a random variable as

a function of the time lag between them.
In this section, we compare theoretical and simulated ACF.

$$A_c(\Delta t) = J_0(2\pi f_D \Delta t) + k_c^2$$

It can be observed that at smaller k_c values i.e, for 0 and 1, there is more correlation than expected in comparison with theoretical. Whereas at larger k_c values like 10, it can be seen that the ACF for both methods is similar to that of the theoretical ACF. This significant change is because ACF is dependent on k_c^2. It can be seen that the correlation increases at points other than zero every time which can be due to the periodicity in both methods.[Figure 5]

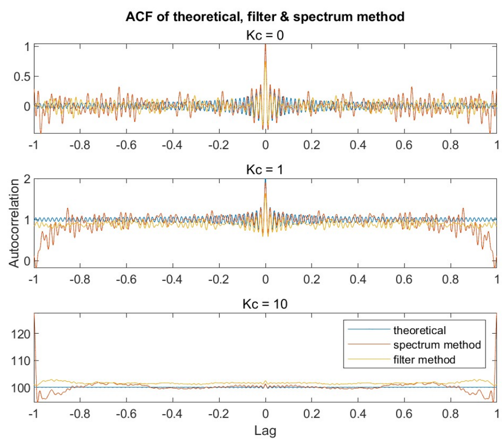


Fig. 5. ACF comparison w.r.t k_c

G. *Comparison between Spectrum method and filter method*

In this section, we compare between spectrum method and filter method w.r.t N_s, f_D and T_s.

- The spectrum method is less complex compared to the filter method because it consists of simple multiplications rather than complex operations like convolution present in the filter method.
- The spectrum method is efficient in removing unwanted higher frequencies when compared to the filter method.
- At larger window size, the spectrum method consumes a lot of memory and requires larger computation capacity and thus making it a slower one compared to the filter method.
- The spectrum method has high signal integrity with less static noise.
- Spectrum methods are estimated using several samples rather than one single sample and therefore, features estimated from signal power spectra would be robust to noise. Furthermore, it is easy to attach physical significance to spectral features.

H. *Time and Frequency-Varying Rician Fading Channels*

In this section, we generate mesh and surf plots for 18 combinations of the spectrum methods with respect to taps(L), normalized Doppler frequency($f_D T_s$) and k_c values and constant time samples $N = 300$ and frequency samples $M = 64$. Where, k_c ϵ [0,1,10] , $f_D T_s$ ϵ [0.1,0.005] and L ϵ [1,2,3].

$$f_D T_s = \frac{T_s}{T_{coh}}$$

where, T_s is the symbol time and T_{coh} is the coherence time.
If

$$T_s \ll T_{coh}$$

then slow fading channel
If

$$T_s \approx T_{coh}$$

then fast fading channel

Thus T_s determines whether the channel is slow-fading or fast-fading.

It can be observed that, for a fixed value of k_c and L, as the value of $f_D T_s$ increases, the fading velocity increases.

If we fix the value of $f_D T_s$ and L and vary k_c, it can be observed that the peak magnitude of the graph increases as the value of k_c decreases. Each sample will have greater power as k_c is raised. Even though the magnitude's peak value is decreased, the number of samples with higher power increases. This is the reason why we have a larger portion of high gain regions in the graph as the k_c value is increased.

In this case, when we change the value of L, keeping $f_D T_s$ and k_c constant, it can be noticed that as the value of L increases the paths of wave pattern increases, this is due to the increase in the number of multi-path components which results in both amplitude and frequency varying patterns. i.e, an increase in the number of taps causes a significant decrease in the coherence bandwidth(B_{coh}) which makes the channel highly correlated. If the signal bandwidth is less than B_{coh}, the channel had nearly the same property over the entire signal bandwidth which makes it a flat-fading channel. Whereas if the signal bandwidth is greater than B_{coh}, the channel changes throughout the entire signal bandwidth which makes the channel to be frequency-selective.

[Figure 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23]

III. Members contribution

In the beginning, we divided the tasks in the project into 4: Rayleigh Fading Channel- Filter method, Rician Fading Channel- Filter method, Rayleigh Fading Channel- Spectrum method, Rician Fading Channel- Spectrum method. In between one team member left the course after 1 week. So the first part is divided into 3. Rayleigh and Rician - spectrum method(Akshay Vayal Parambath), Rayleigh - filter method(Anakha Krishnavilasom Gopalakrishnan) and Rician - filter method(Ann Priyanga Dhas Climent Jackey). The remaining part of the tasks is done together. Also, every team member contributed their part in preparing the project report.

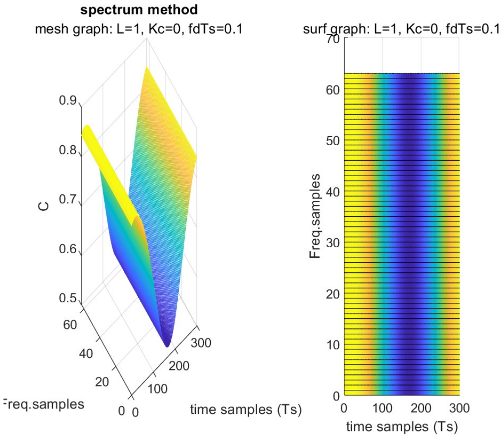
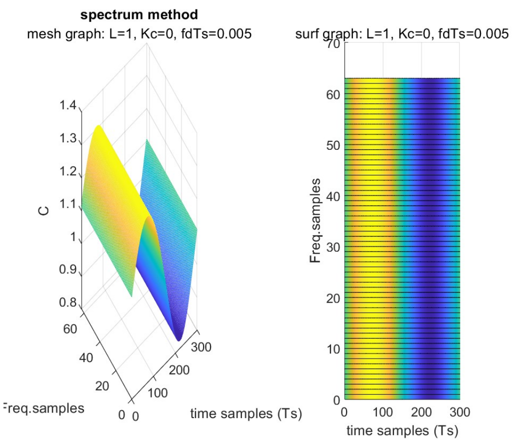


Fig. 6.



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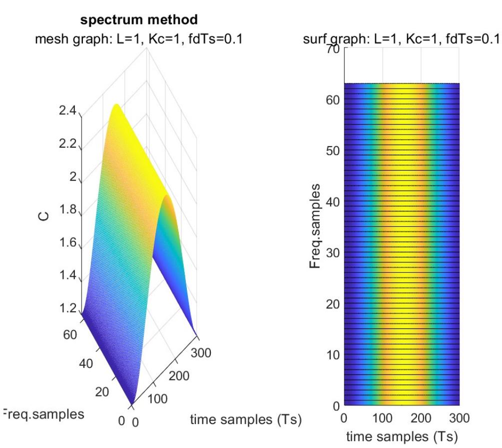
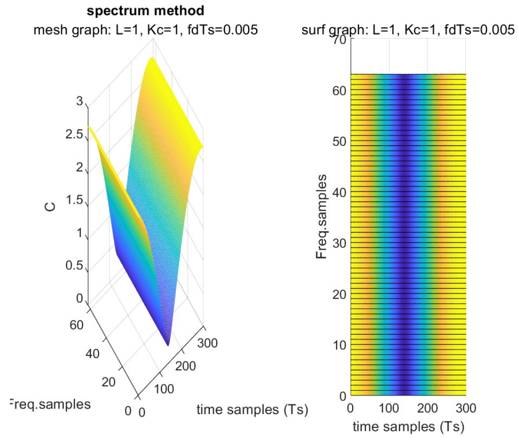


Fig. 8.

IV. References

[1] Goldsmith, Wireless Communications, Cambridge University Press, 2005.



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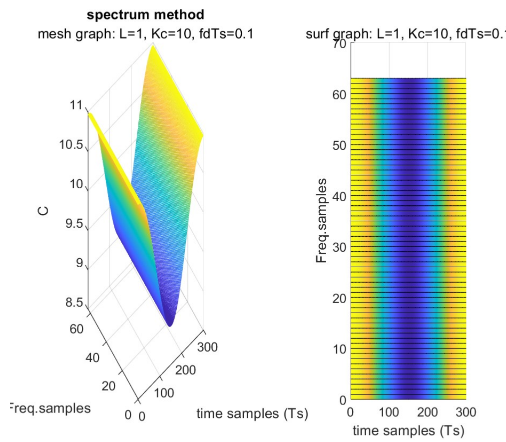

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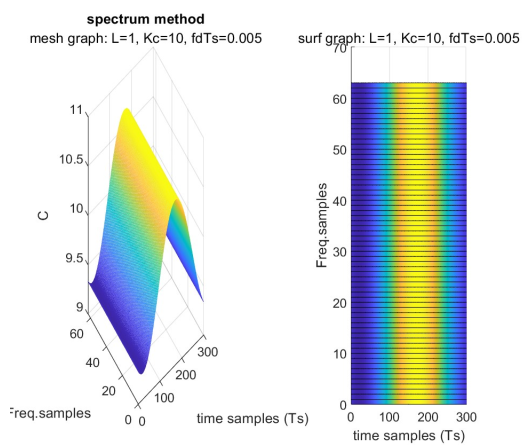

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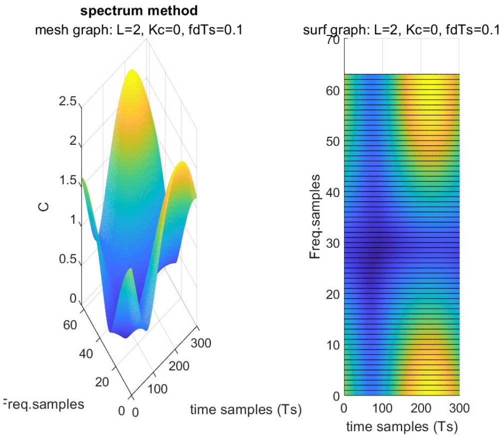

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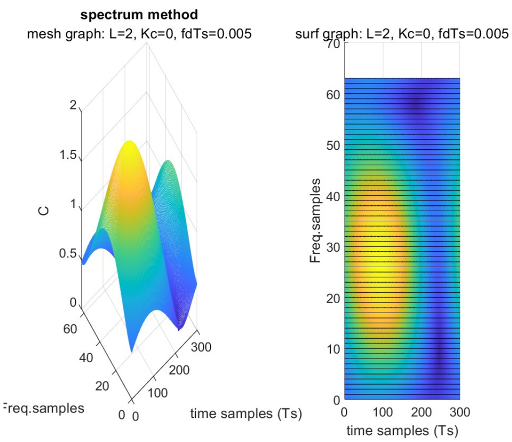

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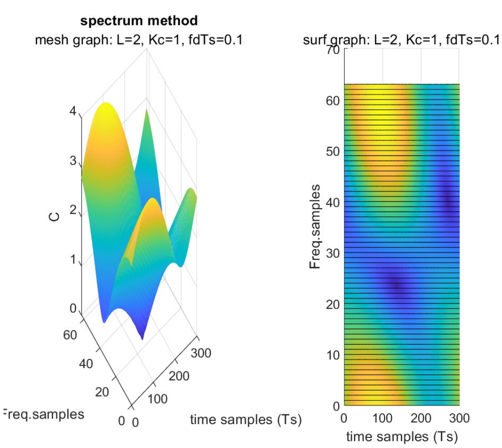

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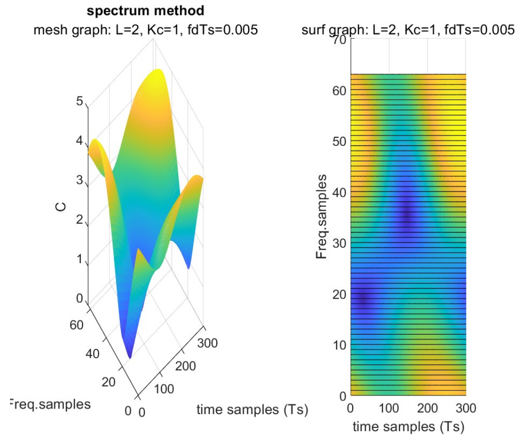

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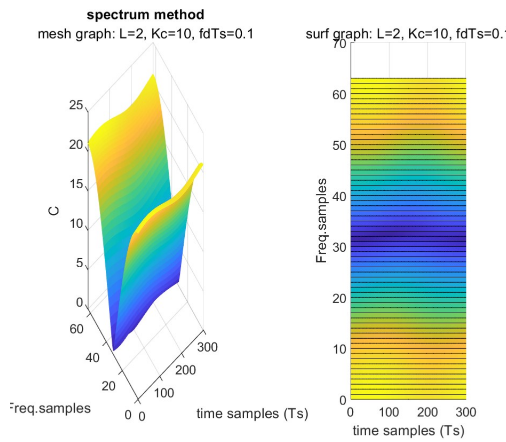

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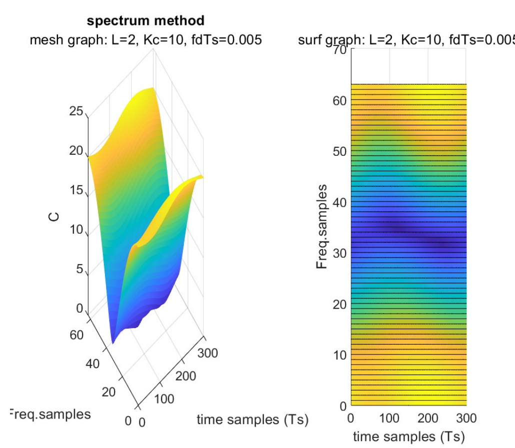

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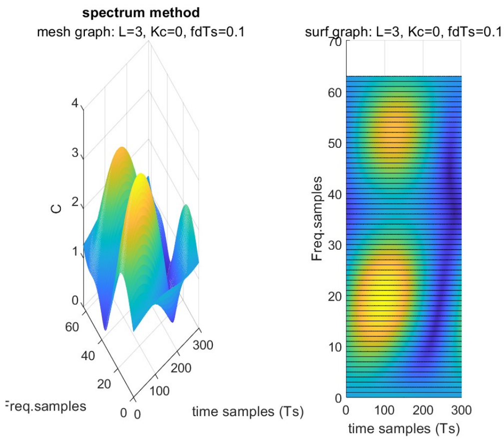

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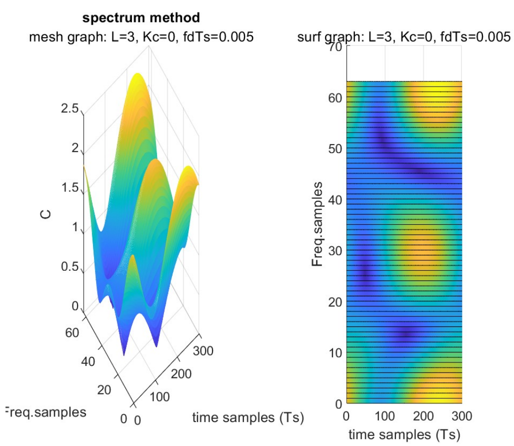

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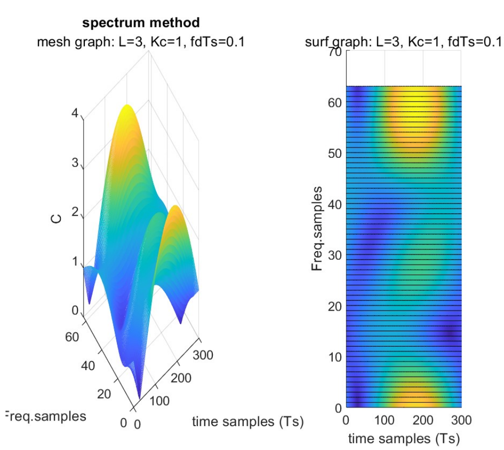

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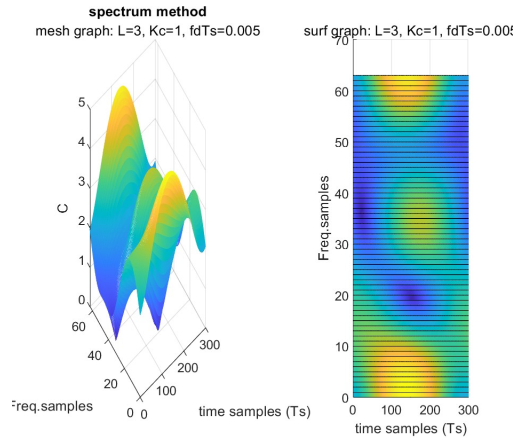

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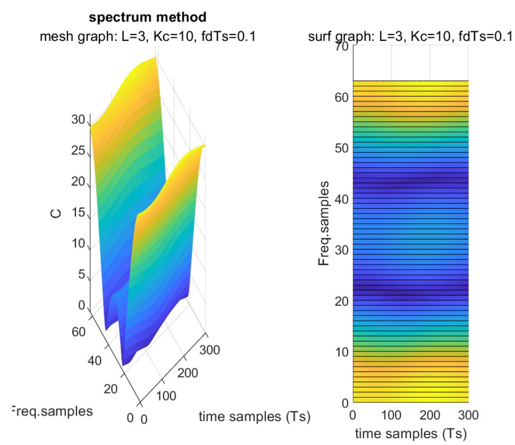

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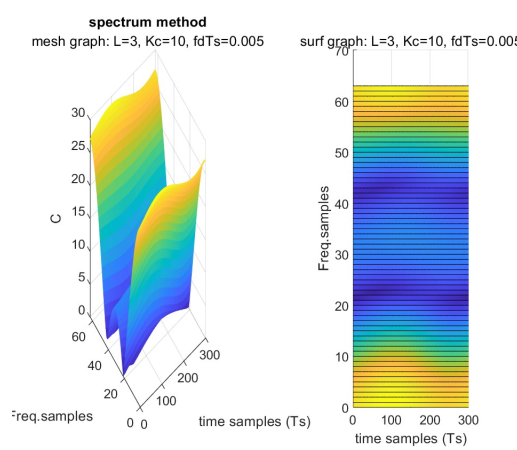

Fig. 23. mesh and surf plots for 18 combinations of the spectrum method with respect to L, $f_D T_s$ and k_c