5G Millimeter wave Bandpass Filter

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Abstract **-** This project involved simulating the performance of Butterworth, Chebyshev type I, and Chebyshev type II bandpass filters for a 5G millimeter wave signal with a center frequency of 2.1 GHz. Spurious signals were added to the signal to test the effectiveness of the filters in removing unwanted signals. The performance of the three types of filters was compared based on their attributes and the effects on removing spurious signals. The results showed that the Butterworth filter has a smooth frequency response with a wider transition band, while the Chebyshev filters have steeper roll-offs with narrower transition bands but introduce ripple in the passband or stopband. The Chebyshev type II filter provided the best attenuation in the stopband but also had a wider transition band. All three filters were effective in removing spurious signals, but the Chebyshev filters provided better attenuation in the stopband. The choice of the best filter type for the 5G millimeter wave system depends on specific requirements, with the Chebyshev filters being a better choice for high spurious signal rejection.

Keywords – Bandpass Filter Performance, Spurious Signal Rejection, Comparative Study of Filter Types

1 INTRODUCTION

Network communication has emerged as a crucial technological innovation in modern society. The advent of 5G, the fifth-generation cellular network, aims to significantly enhance the quality of service by offering faster data rates and lower latency [1]. Compared to the current 4G network, 5G facilitates quicker data processing and transmission, making it applicable in various domains such as IoT, mobile communication, and military systems. Consequently, 5G has become a prominent subject of research.

Table 1 comparison between 4G and 5G

item	4G	5G
max data rate	100Mbps	10Gbps
latency	50ms	1ms
capacity	smaller	larger

The foundation of the 5G network lies in millimeter wave (mmW) technology, which operates within the spectrum band of 30 to 300 GHz and is employed in wireless communication systems [2]. The expansive mmW spectrum enables 5G systems to achieve multigigabit data rates over long distances for point-to-point communication [3]. In contrast to the limited frequency range allocated for cellular systems, typically below 3GHz, the higher frequencies in mmW technology offer a spectrum that is up to 200 times more abundant [2]. This potential has sparked recognition of the significant impact that mmW technology will have on the current mobile cellular system.

Although mmW technology is widely regarded as a prospective candidate for 5G, there are certain drawbacks associated with its current implementation. Due to the higher power and intensified directivity required for mmW antennas, they generate substantial radiation gain. To mitigate this issue and reduce radiation beyond the desired frequency band, a band-pass filter with sharp roll-off, capable of suppressing spurious signals, is essential [4].

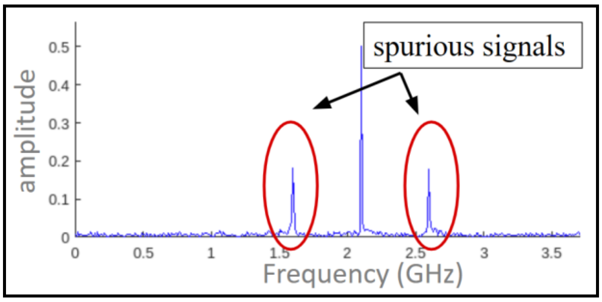

Figure 1 Demonstration of spurious signals as making signals in 2.1GHz

Previous studies have explored the relationship between mmW and 5G technology, but there is a lack of specific research focusing on the simulation and design of bandpass filters, which are vital components in mmW systems. Therefore, this study aims to simulate a bandpass filter for mmW systems. MATLAB will be utilized to simulate mmW signals, and the design of different types of filter will be created. The spurious signals will be added to the simulation to observe the effect on different types of bandpass filter. Additionally, the challenges associated with creating bandpass filters will be discussed, along with potential solutions, in future research.

2 MAIN CONTENT

2.1 METHODS: SIMULATION

The research implemented MATLAB for simulating the bandpass filters. MATLAB provides a comprehensive set of built-in functions and tools for signal processing and filter design, making it a suitable choice for this research. It offers an intuitive and user-friendly environment for developing and analyzing filter designs, enabling us to efficiently explore different filter types and evaluate their performance.

2.2 PROCESS

2.2.1 Define parameters

During the simulation, I utilized three different types of bandpass filters - Butterworth, Chebyshev I, and Chebyshev II - all with the same order. These filters were applied to a 5G wave signal centered at a frequency of 2.1 GHz. In the case of Chebyshev filters, the ripple parameter controls the maximum allowable variation or ripple in the passband or stopband. It is specified in 0.5 decibels (dB) and affects the trade-off between filter steepness and passband/stopband ripple. Additionally, the simulation involved the introduction of spurious signals outside the desired frequency band to assess the filters' capability in eliminating unwanted signals.

```
>> % Define parameters
fc = 2.1e9; % center frequency
fs = 10e9; % sampling frequency
numSamples = 1000; % number of samples
t = (0:numSamples-1)/fs; % time vector

% Generate test signal with spurious signals
signal = 0.5*sin(2*pi*fc*t) + 0.2*sin(2*pi*(fc+0.5e9)*t) + 0.2*sin(2*pi*(fc-0.5e9)*t) + 0.1*randn(size(t));
% Define filter parameters
order = 5; % filter order
Wn = [1.8e9 2.4e9]/(fs/2); % passband cutoff frequencies

% Butterworth filter
[b1,a1] = butter(order, Wn, 'bandpass');
output1 = filter(b1,a1,signal);

% Chebyshev Type I filter
[b2,a2] = cheby1(order, 0.5, Wn, 'bandpass');
output2 = filter(b2,a2,signal);

% Chebyshev Type II filter
[b3,a3] = cheby1(order, 0.5, Wn, 'bandpass');
output3 = filter(b3,a3,signal);
```

Figure 2 the defining parameter in the script

2.2.2 Plotting

The script includes plotting to visualize the time-domain and frequency-domain characteristics of the original signal and the filtered signals. Here's a briefing on the plotting in the script:

•Time Domain Plots:

The script generates three time-domain plots using the `plot` function. These plots allow us to observe the signal waveform in the time domain. The content of the time-domain plots includes time and the amplitude of original signals and filtered signals.

```
>> % Time-domain plots
figure;
subplot(3,1,1);
plot(t, signal, 'b', t, output1, 'r')
xlabel('Time (s)');
ylabel('Amplitude');
title('Filter Comparison');
legend('Original Signal', 'Butterworth Filter');

subplot(3,1,2);
plot(t, signal, 'b', t, output1, 'g')
xlabel('Time (s)');
ylabel('Amplitude');
title('Filter Comparison');
legend('Original Signal', 'Chebyshev Type I filter');

subplot(3,1,3);
plot(t, signal, 'b', t, output1, 'm')
xlabel('Time (s)');
ylabel('Amplitude');
title('Filter Comparison');
legend('Original Signal', 'Chebyshev Type II filter');
```

Figure 3 the time-domain plots in the script

•Frequency Domain Plot:

The script also generates a frequency-domain plot using the `plot` function. This plot provides insights into the frequency response of the filters and the spectral content of the signals. The content of the frequency-domain plot includes:

Magnitude Response: The plot illustrates the magnitude response of the original signal, the Butterworth filtered signal, and the Chebyshev Type II filtered signal. It allows us to compare the spectral content of the signals and observe the filter's behavior in terms of signal attenuation or amplification across different frequency components.

```
>> % Frequency-domain plot
NFFT = 2^nextpow2(numSamples);
f = fs/2*linspace(0,1,NFFT/2+1);
signal_fft = fft(signal, NFFT)/numSamples;
output1_fft = fft(output1, NFFT)/numSamples;
output2_fft = fft(output2, NFFT)/numSamples;
output3_fft = fft(output3, NFFT)/numSamples;

figure;
subplot(3,2,1);
plot(f/(fs/2), abs(signal_fft(1:NFFT/2+1))','b', f/(fs/2), abs(output1_fft(1:NFFT/2+1))','r');
xlabel('Normalized Frequency');
ylabel('Magnitude');
title('Frequency Response Comparison');
legend('Original Signal', 'Butterworth Filter');

subplot(3,2,3);
plot(f/(fs/2), abs(signal_fft(1:NFFT/2+1))','b', f/(fs/2), abs(output2_fft(1:NFFT/2+1))','g');
xlabel('Normalized Frequency');
ylabel('Magnitude');
title('Frequency Response Comparison');
legend('Original Signal', 'Chebyshev Type I filter');

subplot(3,2,5);
plot(f/(fs/2), abs(signal_fft(1:NFFT/2+1))','b', f/(fs/2), abs(output3_fft(1:NFFT/2+1))','m');
xlabel('Normalized Frequency');
ylabel('Magnitude');
title('Frequency Response Comparison');
legend('Original Signal', 'Chebyshev Type II filter');
```

Figure 4 the magnitude response of the frequency-domain plots in the script

Phase Response: The frequency-domain plot also includes the phase response of the signals. The phase response indicates any phase shifts or delays introduced by the filters and aids in understanding the impact of the filters on signal timing.

```
% Plot phase response
subplot(3,2,2);
plot(f/(fs/2), angle(output1_fft(1:NFFT/2+1))','r');
xlabel('Normalized Frequency');
ylabel('Phase (rad)');
title('Phase Response Comparison');
legend('Butterworth Filter');

subplot(3,2,4);
plot(f/(fs/2), angle(output2_fft(1:NFFT/2+1))','g');
xlabel('Normalized Frequency');
ylabel('Phase (rad)');
title('Phase Response Comparison');
legend('Chebyshev Type I filter');

subplot(3,2,6);
plot(f/(fs/2), angle(output3_fft(1:NFFT/2+1))','m');
xlabel('Normalized Frequency');
ylabel('Phase (rad)');
title('Phase Response Comparison');
legend('Chebyshev Type II filter');
```

Figure 5 the magnitude response of the frequency-domain plots in the script

By generating graphical representations of the time-domain and frequency-domain characteristics, we can visually examine the impact of the filters on the signal. This allows us to make comparisons between different filter types and assess their effectiveness in terms of preserving the desired frequency range and suppressing unwanted signals.

2.3 RESULTS AND ANALYSIS

In the scripts, we have applied Butterworth, Chebyshev type I, and Chebyshev type II bandpass filters to filter a 5G millimeter wave signal with a central frequency of 2.1 GHz. Additionally, we have introduced spurious signals outside the desired frequency band to assess the filters' ability to eliminate unwanted signals.

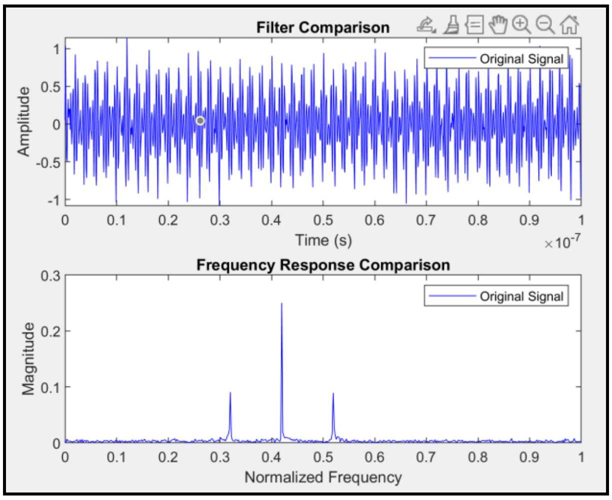

Figure 6 the plots of the testing signals in time domain (top) and frequency response (bottom)

After analyzing the simulated filtered signals, it is evident that all three types of filters exhibit favorable performance in removing spurious signals. However, upon examining the phase response, it is observed that the Butterworth filter has a wider transition band compared to the Chebyshev filters, potentially leading to a slower roll-off in the stopband. In contrast, both Chebyshev filters demonstrate a more rapid roll-off in the transition band when applied to signal filtering. As a result, the Chebyshev filters offer superior attenuation in the stopband compared to the Butterworth filter. Therefore, in situations that necessitate a sharper drop-off and enhanced attenuation in the stopband, the Chebyshev type II filter emerges as the most suitable choice, despite its wider transition band and stopband ripple.

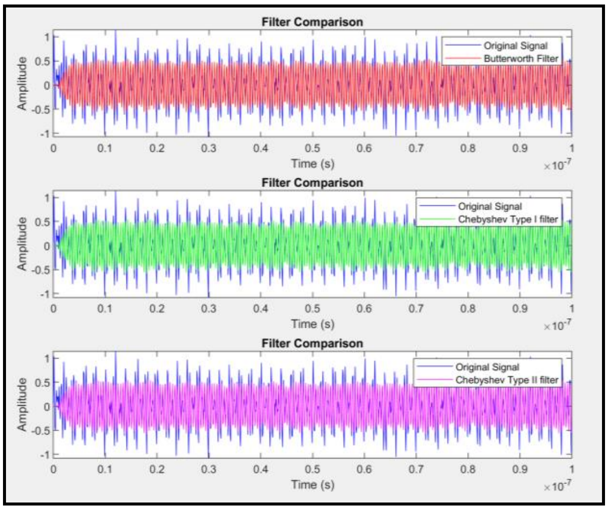

Figure 7 the plots of the filtered signals by three types of bandpass filter(red: Butterworth, green: Chebyshev I, magenta: Chebyshev II) in time domain

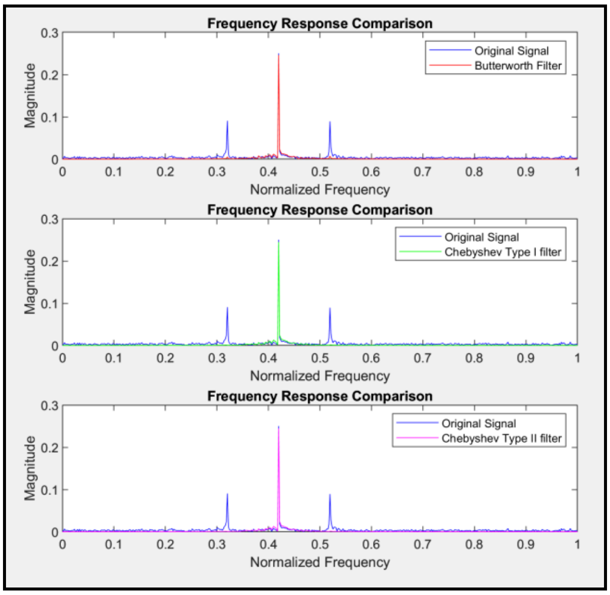

Figure 8 the plots of the filtered signals by three types of bandpass filter(red: Butterworth, green: Chebyshev I, magenta: Chebyshev II) in frequency response

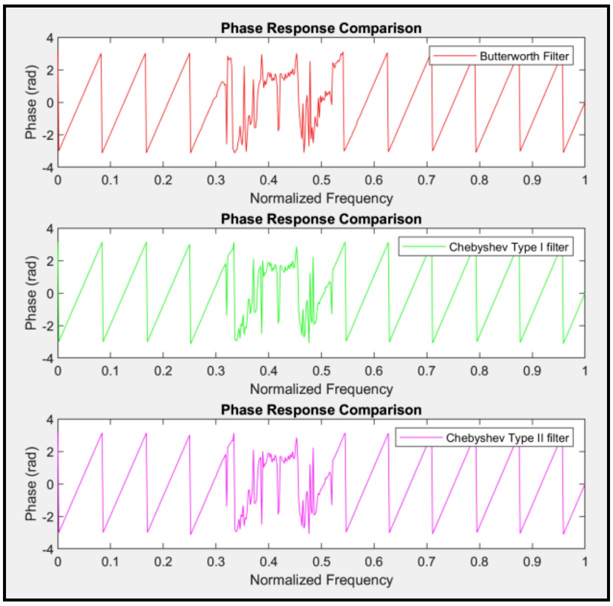

Figure 9 the plots of the filtered signals by three types of bandpass filter (red: Butterworth, green: Chebyshev I, magenta: Chebyshev II) in phase domain

3 CONCLUSION

Through an examination of the frequency domain characteristics of the filters, we can assess their capability to transmit the desired frequency range while diminishing or dismissing unwanted signals. Selecting the optimal filter type is contingent upon the particular needs of the application, encompassing factors like the passband flatness, roll-off steepness, and stopband attenuation.

When it comes to eliminating unwanted spurious signals, the Butterworth, Chebyshev type I, and Chebyshev type II filters have proven to be effective. However, the latter two filter types exhibit superior attenuation in the stopband compared to the Butterworth filter. This indicates that if a high level of spurious signal rejection is required in the 5G millimeter wave system, opting for the Chebyshev type I or Chebyshev type II filter may be more appropriate than using the Butterworth filter.

In conclusion, selecting the optimal filter type for 5G wave signals depends on the specific requirements of the application. In the context of this project, the primary objective is to determine which type of bandpass filter offers the best performance in filtering out spurious signals. Consequently, based on the simulation results, it is evident that the Chebyshev type I and Chebyshev type II filters exhibit superior attenuation in the stopband when compared to the Butterworth filter. In other words, for applications that demand a high level of spurious signal rejection, the Chebyshev type I or Chebyshev type II filter would be the preferable choice.

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