

SAW Filter Modelling in Matlab for GNSS Receivers

Syed Haider Abbas, Hussnain Haider, Muhammad Faheem Siddique and Awais Ahmed

Electrical Engineering Department, Sarhad University of Science and Information Technology, Peshawar, Pakistan

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ABSTRACT

Satellite navigation has enabled a great amount of new application for many users, but a lot of limitations have been observed regarding precision and integrity of navigation signals. Overall signals of different navigation systems (GPS, GALILEO, GLONASS signals) compose Global Navigation Satellite Systems (GNSS) Signal. Each of the satellite system has separate signal characteristics, but each signal needs to be compatible with the others to prevent interferences and attenuations between signals. The processing of all the signals is performed in same receiver. Hence, complex receiver design is required. In GNSS signals different frequencies are used for different satellite navigation systems such as GPS, Galileo and Glonass. When the group delay response is observed in SAW filters it shows that the signals lie on different frequencies have different delays. Manufacturers carried out measurements with respect to carrier wave but they have ignored the spreading codes or modulation. In this research, we will design a model for GNSS SAW filter in Matlab. This model can be use to observe the delay of the signals. This model will allow the manufacturers to address these problems in the SAW filter software to optimise slope and magnitude of the design which will benefit the users of GNSS all over the world to get more precise positioning.

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Corresponding Author:

Syed Haider Abbas,

Electrical Engineering Department, Sarhad University of Science and Information Technology

Peshawar, Pakistan.

Email: habbas33@gmail.com

1. INTRODUCTION

In last 15 years, many important events are occurred in field of satellite navigation system and today many satellite navigation systems exists such as modernised GPS, Galileo, Glonass and Compass. GNSS is basically interoperability between various satellite systems which is used by the public without taking the nationalities of different systems in account.

Most of the satellite navigation applications today are based on the U.S GPS system which was initialized by U.S Department of Defence. This 30 year old system became available to the civil community in 1993. This system is adequate for most of the end user applications but still it has few limitations when accuracy and integrity is concerned. The military influence on GPS means that the civil body can be cut off in the time of trouble. [2]

This insufficiency of accuracy and reduced integrity made the consumer to demand more accurate positioning system which lead to the modernization of navigation system. Hence the next generation satellite will employ more steering signals to allow improved performance, better precision, accessibility and signal redundancy. GPS, Glonass and Galileo will be independent systems but using all infrastructures will present more advantages in terms of precision and security. This will encourage the development of new applications which require more accurate positioning. The modernized Global navigation satellite system will benefit all users by using the same receiver for GPS, Glonass and Galileo signals. Moreover, incorporated systems have

the benefit to guarantee secure, reliable and independent operations whenever GNSS signal is vanished due to interference system failure or government actions.

In this paper two different techniques to model the SAW filter in Matlab were used and a Simulink model is presented to show the frequency and groupdelay response. Remez algorithm was first implemented but due to its limitations s-parameters were then used model the SAW filter design.

2. SAW FILTER MODELLING

To model the SAW filter in matlab we have investigated two techniques. First one known as Remez algorithm is a technique that is widely used optimized technique for the SAW filters which can be implemented using the remez algorithm. The second technique is by reading s2p format file in the matlab and extracts the s-parameters to compute the magnitude phase and delay response.

2.1. Remez Algorithm

Remez Algorithm also known as Remez exchange algorithm was proposed by Evgeny Yakovlevich Remez, is used to find approximations to functions using iterative multivariable methods. It gives the better results for approximation problems than other methods like minimax algorithm.[3]

It begins with the function f to be approximated with a set N of $n+2$ samples x_1, x_2, \dots, x_{n+2} in the approximation interval, where chebyshev linearly mapped to the interval.

For the best approximation solve the equation

$$\mathbf{b}_0 + \mathbf{b}_1 x_1 + \dots + \mathbf{b}_n x_n^i + (-1)^i \mathbf{E} = f(x_i)$$

(where $i = 1, 2, \dots, n+2$)

for the unknowns $\mathbf{b}_0, \mathbf{b}_1, \dots, \mathbf{b}_n$ and \mathbf{E} .

2.1.1. Remez Algorithm for SAW filters

As apodized transducer is closely related to transversal filter the established methods for transversal filter can be applied. In saw transducer the electrodes or fingers provide the ability to sample the saw and distance between electrodes provide relative delay.

We can implement saw filter using Remez algorithm which is an optimized method widely used for design of digital FIR filters and SAW filters.

Whats the key?

- The optimized method here doesnot involve generating an impulse response and then sampling it. Hence no complex coding is required for programming.
- Just have to specify the desired amplitudes at specified frequency points.
- Remez algorithm guaranteed to find the optimum solution for the filter coefficients
- Matlab provides the function for Remez algorithm.

Every filter has a pass band and a stop band as shown (for LPF)

- Passband $W < W_p$
- Stop band $W > W_s$
- Transition band $W_p < W < W_s$

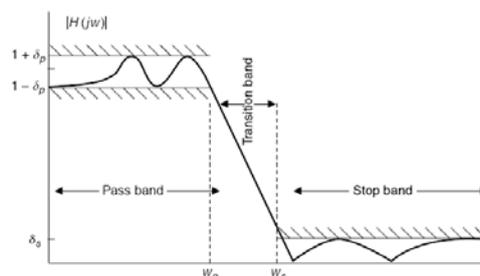


Figure 1. Pass and Stop band of a typical filter

Now Remez algorithm finds filter coefficients using specified magnitudes over the range of corresponding frequency.

Matlab provides family of functions to implement Remez algorithm as shown

```

hn = remez (L, f, mag)
hn = remez (L, f, mag, wei)
hn = remez (L, f, mag, 'filtertype')
hn = remez (L, f, mag, wet, 'filtertype')

```

The output hn is the $L+1$ coefficients of order L , where f shows the frequency over the range $0 \leq f \leq 1$ with a sampling frequency of 2Hz and the magnitudes are given as mag for the corresponding frequency [4]. For example a normalized multi level filter spec is shown below

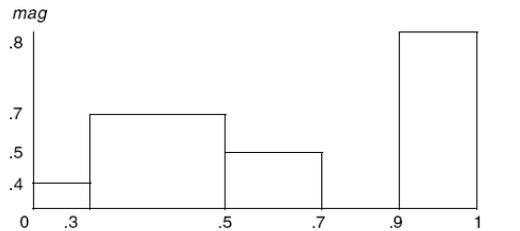


Figure 2. Defining pass and stop bands
 $F = [0 \ .3 \ .5 \ .7 \ .9 \ 1]$
 $Mag = [.4 \ .7 \ .5 \ 0 \ .8 \ .8]$

The result of remez function can be used to find the frequency response of the filter.

First we need to define the bands and their magnitudes. Frequency and its corresponding amplitude is stored in separate vector. We also need the number of finger pairs as L in the algorithm because in saw transducer is number of fingers provides sampling. Remez algorithm in matlab performs the computation for us and gives the filter coefficients which can be used to find the frequency response and group delay.

2.1.2. Limitations

The filter coefficients required to model the SAW filter in matlab was not available as I have to model the saw filter using the s parameter data provided by the manufacturer. Therefore this technique was not perused further for the filter modelling.

2.2. Modelling Using S-Parameters

The other method investigated was to model the saw filter in matlab by reading a touch stone file in matlab and extract s -parameters of the filter to form an RF component in matlab. This method was more beneficial because we can take the s -parameter measurements in the Vector Network Analyser. VNA measurements for S_{21} were taken and noted for the SAW filter and then used in the matlab for simulation. The measurements were stored in touchstone file format which is used world wide as n -port network data.

Matlab provides `rfcckt.passive` function to construct a passive component this function reads the passive object data from the touchstone data file to represent the component. This component contains network parameter data and frequency which is extracted from the `s2p` file The passive component is then used to plot the transfer function using `s2tf` matlab function which calculates the voltage transfer function from source voltage to load voltage using equation [5].

$$TF = VL/VS = S21 * (1 + GAMMAL) * (1 - GAMMAS) / (2 * (1 - S22 * GAMMAL) * (1 - GAMMAIN * GAMMAS))$$

Where Also $GAMMAL$, $GAMMAS$ and $GAMMAIN$ are the reflection coefficients

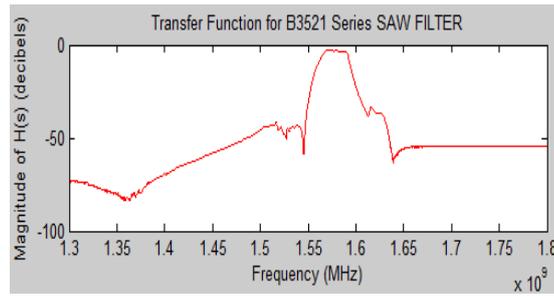


Figure 3. SAW B3521 transfer function using Matlab

When the groupdelay is extracted from the s-parameters it will be nearly constant for over the small variation of frequencies. It can also be described as the transit time of a network [6].

To calculate the groupdelay all the s21 data is first stored in separate vector and its phases are unwrapped and converted to degrees [7], then the groupdelay is calculated as

$$\text{Grpdelay} = -(\text{diff}(\text{Phase}) ./ (\text{diff}(\text{Freq}))) ./ 360$$

Where $\text{diff}(x)$ is the difference between adjacent elements of x . If X is a matrix, then $\text{diff}(X)$ returns a matrix of row differences:

$$[X(2:m,:)-X(1:m-1,:)]$$

The plots of groupdelay for both saw filter using above function are shown below.

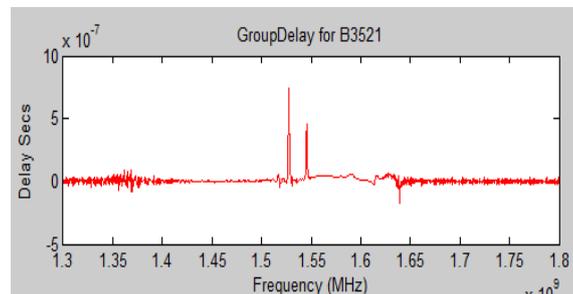


Figure 4. Group delay for SAW B3521 using Matlab

3. SIMULINK MODEL

In simulink it was easy to track the input required for each blockset. Moreover, it is less time consuming to make any changes in your design. Switching from a programming based design to a model based simulation design made the presentation of my design easier as most of the blocks are self explanatory.

To make SAW filter design in simulink RF Blockset was used, which contains a library of blocks needed to model an RF system. These RF block are used to represent different components (amplifiers, filters, mixers and transmission lines etc) of an RF System. We can use these components with various depictions of network parameters (H, Z, S and Y parameters) where u can observe different plots and smith charts for these network components. The simulink computes your RF model in time domain with complex baseband representation.

To design the system we have selected an RF block called General passive Network which is used to model a 2-port network element which can be describe by a data file (touchstone format). It uses the interpolation method to figure out the values of s-parameters with respect to its modelling frequency. This block also converts the network parameters represented in Z or Y to s-parameters. To read our data s2p format file we provide the location and file name to the block by browsing it While setting the block parameters. We can also visualise different plots (S11, S21, S22, S12 and their magnitude, group delay and phase) for the data file.

For every RF system we need an input output ports which provides the connection between simulink and RF physical blocks [8]. This input port gives the parameter data required to calculate the modelling frequency and the baseband equivalent impulse response of the system. Where the output port generates a baseband equivalent time domain response of the incident signal with the RF network components. To calculate the Baseband equivalent impulse response the input port block parameters and the s-parameters interpolated from the data file is used. First it determine the modelling frequencies which are the function of centre frequency (f_c), the sample time and filter length N of finite impulse response specified in input port block.

After connecting the blocks for input signal my block diagram is as shown

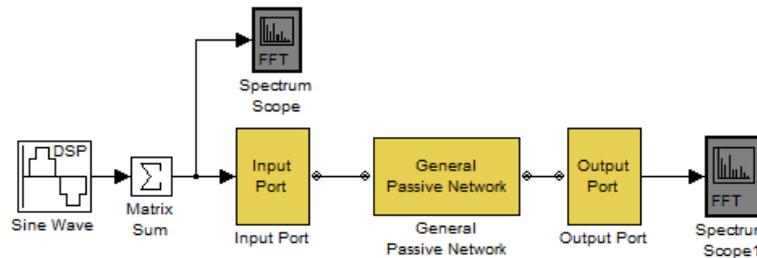


Figure 5. Simulink model for the SAW filter design

In this block diagram the Sinewave generates the complex source signal. We can also create two or three tone signals in different channels which can be combine into one single source using the matrix sum. Frequency shift is required for The RF Blockset algorithm in the simulink blocks for the input signal because the simulation is performed using a complex-baseband modelling technique, where filter response is shifted and centres to zero therefore the frequencies of the signals outside RF subsystem must be shifted accordingly. Hence, if the centre frequency of RF component is 1550MHz it means that my input carrier signal of 0Hz will be shifted to 1550MHz so we need to provide a carrier of 25.42 MHz if we intend to create a carrier for 1575.42MHz by setting the frequency of the sinewave block to 25.42MHz output complexity as complex and sampling time $1/200e6$. The result can be seen in spectrum scope at both input and output end. The spectrum scope displays the input signal in frequency domain while the spectrum scope 1 shows the filtered signal. After simulation the results can be seen as shown.

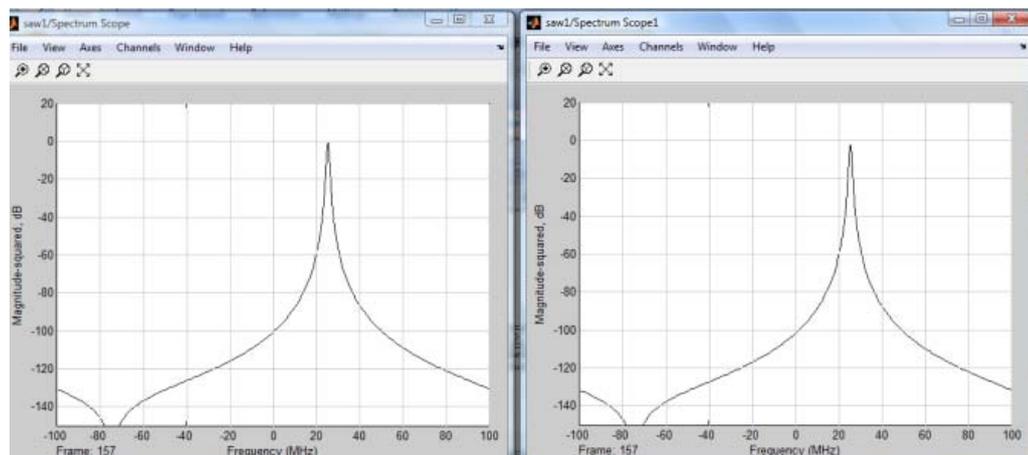


Figure 6. Carrier signal a 1575.42MHz before and after passing through the saw filter

In the above plots 0 MHz represents centre frequency 1550 MHz. As the frequency falls in the pass band therefore we cannot see any attenuation in the signal after passing through the filter. Now let's create a multi tone carrier signal at 1540MHz and 1575MHz and pass it through the filter.

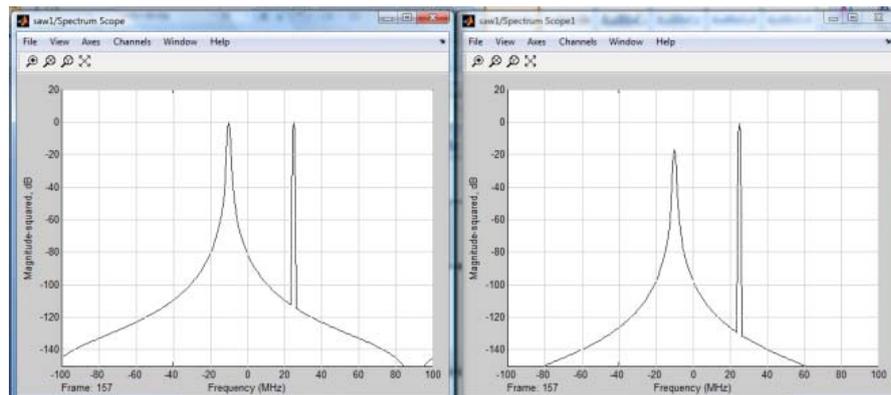


Figure 7. Multicarrier signal at 1540 MHz and 1575 Mhz before and after passing through the SAW filter
 In the plots above we can observe that the signal at 1540 MHz is dropped to a -20 dB which can also be seen at the magnitude response where we can se 20dB drop at 1540 Mhz frequency.

4. FFT TECHNIQUE TO OBTAIN TRANSFER FUNCTION

To compute the transfer function i used another approach to check my filter response using other methods than s-parameters. FFT based transfer function is extremely useful and is one of the commonly used methods in network analysis transfer function of the network is measured from the input signal and the output response of the network as shown

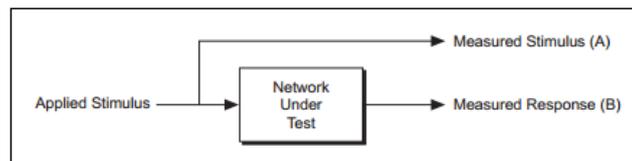


Figure 7. A and B signals needed for the transfer function

Therefore, transfer function can be computed as

$$\text{Transfer Fxn } H(F) = \frac{\text{Cross Power Spectrum (Stimulus, Response)}}{\text{Power Spectrum (Stimulus)}}$$

$$= \frac{S_{AB}(f)}{S_{AA}(f)}$$

Where A is the input signal and B is the response of the network. While using this technique we need to take many transfer function reading and average their results [9]. To compute the transfer function my block diagram is as shown below

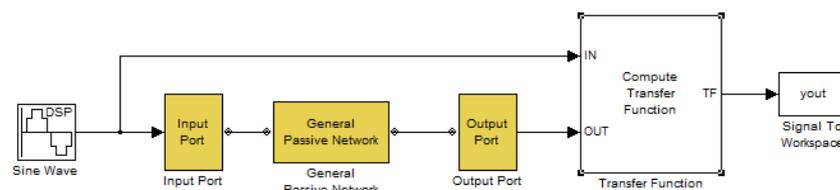


Figure 8. Computing transfer function for Simulink design

The output of the transfer function is plotted in matlab workspace because sinks or plotters in simulink are unable to plot the graphs therefore we need your signal to workspace where it creates a matrix of transfer function values at corresponding frequencies. The transfer function which we have computed using this method is shown as below.

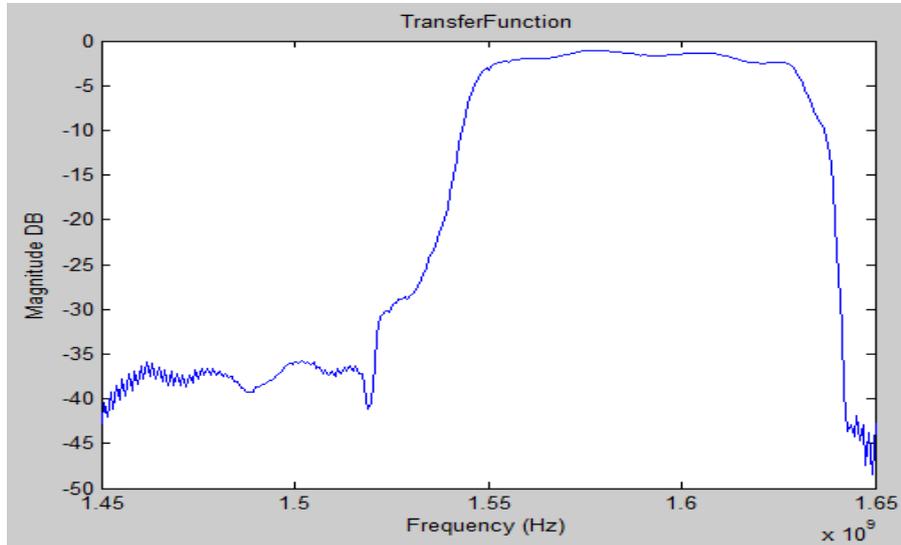


Figure 9. Transfer Function computed from Simulink design

Group delay of the system can also be computed by unwrapping the phase of the transfer function and applying group delay function. The following graph shows the group delay response of the filter.

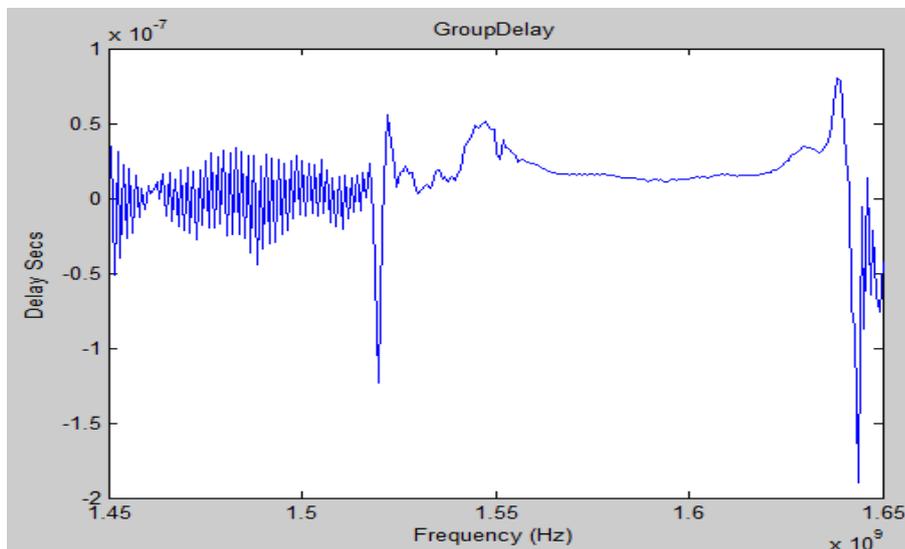


Figure 10. Group delay computed from simulink design

The effect of signal delay on the receiver can be seen from the group delay response of the filter as different delays can be seen in the GPS and Glonass parts of the signal as shown

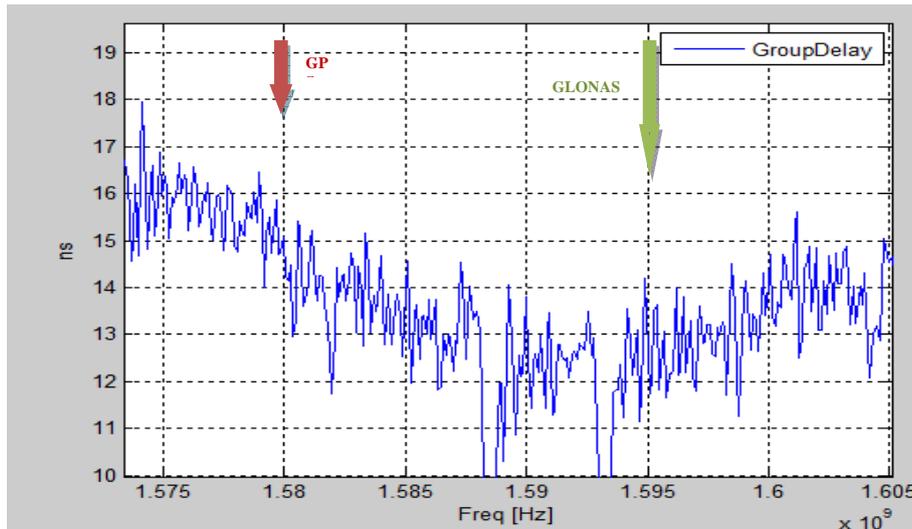


Figure 11. Investigating the GPS and Glonass frequencies and their delays

Due to interpolation of the initial measurements there are fluctuations in the plot. The figure shows that at 1575MHz we have delay of around 16ns while at 1602MHz the delay is noted to be at 14.5 ns. In addition, we can observe different slopes which are negative at GPS frequency and positive at Glonass.

5. CONCLUSION

Different techniques were tried to model the SAW filter in the Matlab. The effective method was using s-parameters and building an RF component to work on. Remez algorithm is effective when the coefficients of the filters and the pass stop bands are known. Simulink model is tried to use the graphical interface to understand the design block by block.

Measurements were taken for the SAW filter using VNA where the s-parameters were again used for the matlab modelling. FFT method is also exercised to compute the response of the filter using the input and output of the RF component. This was important to verify the behaviour of the RF device and not to depend on the s-parameters for the measurements.

The Simulink model showed that the carrier and multicarrier is passing through the RF device. Hence, the approach to model the filter is able to provide base for passing various signals and calculating the delay.

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