

Analysis on High Data Rate Filter Design for Satellite Communication

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Abstract: The paper presents the high data rate filter design for satellite communication using MATLAB. In this work, we considered only the numerical analysis for digital filter design based on the mathematical modeling of the filter design implementation. Result shows that operating frequency of IFIR filter is more than 5 times of that of IIR filter and when it is used in demodulator then the system operating frequency increase by 3 times to that of corresponding IIR filter based demodulator.

Keywords: High Data Rate Filter, DSP, Satellite Communication, Filter Design, Analysis

1. Introduction

As a general design rule any module having feedback in its structure, limits the operating frequency of complete system. In high data rate applications it is very important to choose the suitable structure for each module in a system. Digital filters play an important role in communication system. They utilize maximum hardware resources and in turn decide the operating frequency of a DSP based communication system. A DSP based BPSK demodulator using FIR filter is an ideal choice for carrier/sub carrier demodulation in satellite. Because of huge hardware requirement for FIR filter, option of using upon the behavior of N-tap non recursive linear phase FIR when IIR or Interpolated FIR (IFIR) filters is explored. IIR filter has a advantage of programmability, but the operating frequency of the system is limited by its feedback loops. On the other hand IFIR is equivalent of FIR with reduced hardware and no feedback loop in structure. An IIR based BPSK demodulator that can go up to a data rate of 16Kbps for PCMPSK/PM scheme has been realized. For some payload operations in satellite & also for ground application higher data rate demodulators are required. Using IFIR filter, the same demodulator can be used for those applications. The paper describes one of the applications of

IFIR filter in realizing the 500Kbps BPSK demodulator. In first section general design of an IFIR filter is discussed followed by description of an IR filter. There are many reasons why IFIR filters are very attractive for digital filter design. Some of them are:

1. Simple robust way of obtaining digital filters
2. Inherently stable when implemented non recursively
3. Free of limit cycles when implemented non recursively
4. Easy to attain linear phase
5. Simple extensions to multi-rate and adaptive filters
6. Relatively straight-forward to obtain designs to match custom magnitude responses
7. Some vendors and specialized hardware only support FIR
8. Low sensitivity to quantization effects compared with many IIR filters

In some cases, IFIR filters are considered inefficient in the sense that they require a high-order transfer function to satisfy the system requirements when compared to the order required by digital filters with infinite-duration impulse response. However, IFIR digital filters do possess a few implementation advantages such as possible exact linear-phase characteristic and intrinsically stable implementations, when using non recursive realizations. In addition, the computational complexity of IFIR digital filters can be

reduced if they are implemented using fast numerical algorithms such as the fast Fourier transform.

The IFIR filter can implement narrowband low pass filter design with significantly reduced computational workload relative to traditional FIR filters. The structure of an IFIR

filter design is illustrated in Figure 1. The input or excitation $x(n)$ is bounded input signal. When the bounded input signal is processed according to the output or response by using IFIR filter system $H_{IFIR}(f)$ [1-11].

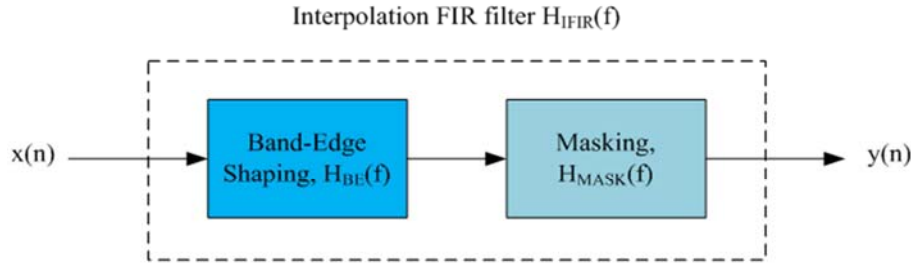


Figure 1. The Structure of an IFIR Filter.

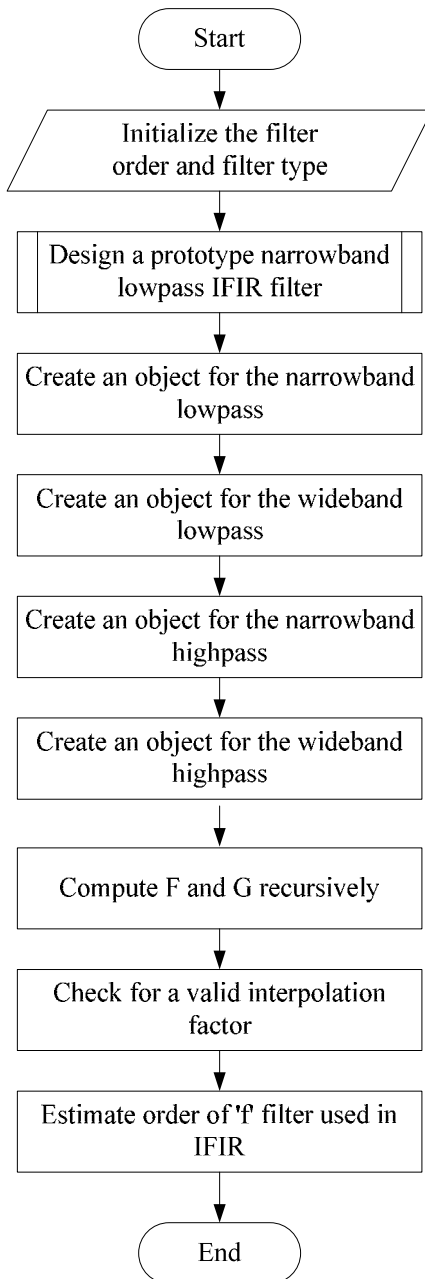


Figure 2. System Flowchart for IFIR Filter Analysis.

2. Flowchart of FIR Digital Filter Design Analysis

According to the literature survey on the IFIR lowpass filter design analysis, the high data rate filter for satellite communication system can be developed with the appropriate design step. The system flowchart for IFIR lowpass filter analysis is illustrated in Figure 2. In this flowchart, there are a lot of processes to accomplish the IFIR low pass filter design. Firstly, the filter order and type are initialized and the subroutine from MATLAB is applied to design a propotype narrowband lowpass IFIR filter. And then the object for narrowband lowpass and high pass filter. The F and G values are recursively analyzed to estimate the “f” filter used in IFIR lowwpas filter analysis.

3. Development of IFIRMAIN.m Script

The main funtion for IFIR lowwpas filter design analysis are combined with the following instructions. The maximum filter order must be 6 and type of digital filter is “low”. The filter analysis can be accomplished to IFIR high data rate filter by applying the filter design tool in MATLAB [12-15].

```

[bup,bimg]=IFIRDESIGN(6,'low',[.12 .14],[.01 .001]);
H = dfilt.dfir(bup); G = dfilt.dfir(bimg);
hfv = fvtool(H,G);
legend(hfv,'Unsmamples Filter','Image Suppressor Filter');
Hcas = cascade(H,G);
hfv2 = fvtool(Hcas);
legend(hfv2,'IFIR Filter Design');
  
```

4. Development of IFIRDESIGN.m Script

Interpolated FIR filter design is found a periodic filter $H(z^L)$ where L is the interpolation factor and an image-suppressor filter $G(z)$ such that the cascade of the two filters represents the optimal minimax FIR approximation to the desired response specified by TYPE with bandedge frequencies contained in vector F while not exceeding the

maximum deviations or ripples (in linear units) specified in vector DEV. TYPE must be a string with either 'low' for lowpass designs or 'high' for highpass designs. F must be a two-element vector with passband and stopband edge frequency values. For narrowband lowpass filters and wideband highpass filters, $L \cdot F(2)$ should be less than 1. For wideband lowpass filters and narrowband highpass filters, $L \cdot (1 - F(1))$ should be less than 1.

DEV must contain the peak ripple or deviation (in linear units) allowed for both the passband and the stopband, i.e., it also must be a two-element vector. IFIDDESIGN returns a delay D that must be connected in parallel with the cascade of $H(z^L)$ and $G(z)$ in the case of wideband lowpass and highpass filters. This is necessary in order to obtain the desired response.

To design a prototype narrowband lowpass IFIR filter the instruction may have been modified as needed

```
[f,g] = narrowBandLp(L,F,DEV,optlevel,forceEven);
switch designType,
    case 'narrowBandLp',
        % Create an object for the narrowband lowpass
        [f,g,d] = designnl(f,g,L);
    case 'wideBandLp',
        % Create an object for the wideband lowpass
        [f,g,d] = designwl(f,g,L);
    case 'narrowBandHp',
        % Create an object for the narrowband highpass
        [f,g,d] = designnh(f,g,L);
    case 'wideBandHp',
        % Create an object for the wideband highpass
        [f,g,d] = designwh(f,g,L);
end
```

To develop the designnl function, the creation of an object for the narrowband lowpass are needed to modify as follows:

```
% Upsample f, create  $F(z^L)$ 
f = upsample(f,L);
% Remove trailing zeros
f = f(1:end - (L-1));
d = []; % Not used for narrowband lowpass
```

To create an object for the wideband lowpass and create two parallel branches, one with a narrowband highpass and one with a delay the -f is needed because of the negative sign of this branch entering the adder

```
d = [zeros(1,(length(f)+length(g)-2)/2,1)]; % Delay
```

To create an object for the narrowband highpass, the below instructions are as follows:

```
if rem(L,2),
    % Find  $F(-z)$  first
    f(2:2:end) = -f(2:2:end);
end
```

```
% Now upsample
f = upsample(f,L);
% Remove trailing zeros
f = f(1:end - (L-1));
% Find  $G(-z)$ 
g(2:2:end) = -g(2:2:end);
M = length(f) + length(g) - 2;
```

```
if rem(M/2,2) == 1,
    % Must add a negative 1 factor to branch1
    f = -f;
end
```

```
d = []; % Not used for narrowband highpass
```

To create an object for the wideband highpass and create two parallel branches, one with a narrowband lowpass (entering with a minus sign to the adder) and one with a delay the -f is needed because of the negative sign of this branch entering the adder.

```
d((length(f)+length(g)-2)/2+1) = 1; % Delay
```

To design a prototype narrowband lowpass IFIR filter, the lowpass response appropriate for firpm can be defined as

```
A = [1 1 0 0];
switch optlevel,
    case {'simple','intermediate'},
        if forceEven,
            minStr = 'mineven';
        else
            minStr = 'minorder';
        end
    case 'advanced',
        % Estimate required orders for F and G
        N1 = estimatefirord(L,F,A,DEV);
        N2 = estimatefirqord(L,F,DEV);
```

To test the min stopband attenuation, the system function $H(z)$ can be got from the following instructions.

```
[H,w] = freqz(upsample(f,L));
H = H.*freqz(g);
```

To compute the gain value g for IFIR lowpass filter, there are two case for switch condition.

```
switch lower(optlevel),
    case 'simple',
        s = warning('off', 'filterdesign:firgr:finalFilterOrder');
        g = firgr(minStr, [0 F(2) 2./L-F(3) 1],A, [DEV(1)./2 DEV(2)]);
    case 'intermediate',
```

To improve the order of G in some cases by including don't care regions, the following instruction can be used.

```
g = computeintermediateg(L,F,DEV,minStr);
```

To compute do care and don't care regions for g, the following instructions are needed.

```
Fg = gFreqIntervals(F,L);
Ag = [1 1 zeros(1,length(Fg)-2)];
DEVg = [DEV(1)./2 DEV(2)*ones(1,(length(Ag)-2)./2)];
```

To analyze the recursive design for iterations, the old values of f and g are first initialize.

```
fold = [1,zeros(1,N1)];
gold = zeros(1,N2+1);
```

And the first iteration can be started as follows:

```
gnew = iterateg(N2,L,fold,F);
fnew = iteratef(N1,L,gnew,F,DEV);
```

The limitation and range of maximum iteration are specified by 100 as shown in the following instructions.

```
tol = 1e-10;
iter = 0;
maxiter = 100;
```

And the old baselines are updated according to the new value of g based on the new values of f .

```

gold = gnew;
% Compute new G
gnew = iterateg(N2,L,fnew,F);
% Update old baselines
fold = fnew;
% Compute new F
fnew = iteratef(N1,L,gnew,F,DEV);
iter = iter + 1;
To check for increasing frequencies, the following
instructions are applied to determine the design type and
convert specification to narrow lowpass frequency range.
if any(diff(F) <= 0),
    msg = 'Frequencies must be specified in increasing
order.';
    return;
end
% Determine design type and convert spec to narrow
lowpass
[Fout,forceEven,designType,DEV,msg] =
determineTypeNSpecs(L,designType,F,DEV);
if ~isempty(msg),
    return;
In the step of determine, appropriate algorithm to use for
IFIR lowpass filter can be analyze by using the following
instructions.
msg = "";
stropts = {'simple','intermediate','advanced'};
indx = find(strncmpi(optlevel,stropts,length(optlevel)));
if isempty(indx),
    msg = 'Unrecognized optimization level specified.';
    return;
end
optlevel = stropts{indx};
To determine if lowpass or highpass, the following codes
are applied.
designOpts = {'low','high'};
designIndx =
find(strncmpi(designType,designOpts,length(designType)));
if isempty(designIndx),
    msg = 'Design type must be "LOW" or "HIGH".';
    return;

```

To determine if narrow-band or wide-band design, the switch case is very efficient method for IFIR lowpass filter analysis.

```

switch designType,
case 'low',
    if F(2) < 1/2,

```

```

        designType = 'narrowBandLp';
    else
        designType = 'wideBandLp';
        Fout = [0,1-F(2),1-F(1),1];
        DEV = fliplr(DEV);
        forceEven = 1;
    end
case 'high',
    if F(2) < 1/2,
        designType = 'wideBandHp';
        forceEven = 1;
    else
        designType = 'narrowBandHp';
        Fout = [0,1-F(2),1-F(1),1];
        DEV = fliplr(DEV);
        forceEven = 1;
    end
end

```

Finally, to check for a valid interpolation factor, the `interperr` instruction for switch case should be utilized as follows:

```

interperr = 'The interpolation factor L is too large for the
frequency specs.';
switch designType,
case {'narrowBandLp','wideBandHp'},
    if L * F(2) >= 1,
        msg = interperr;
        return;
    end
case {'narrowBandHp','wideBandLp'},
    if L * (1-F(1)) >= 1,
        msg = interperr;
        return;
    end
end

```

5. Simulation Results for Comparison of Unsampld and Sampled Filter

The simulation results for high data rate filter design are separated by two portions. They are response of unsampled and image suppressor filter analysis and response of IFIR filter. The first one is comparison of unsampled and sampled filter.

5.1. Magnitude Response for Unsampled and Image Suppressor Filter

According to the specified parameters, the IFIR filter order for lowpass situation is selected by six orders and other declarations in MATLAB script.

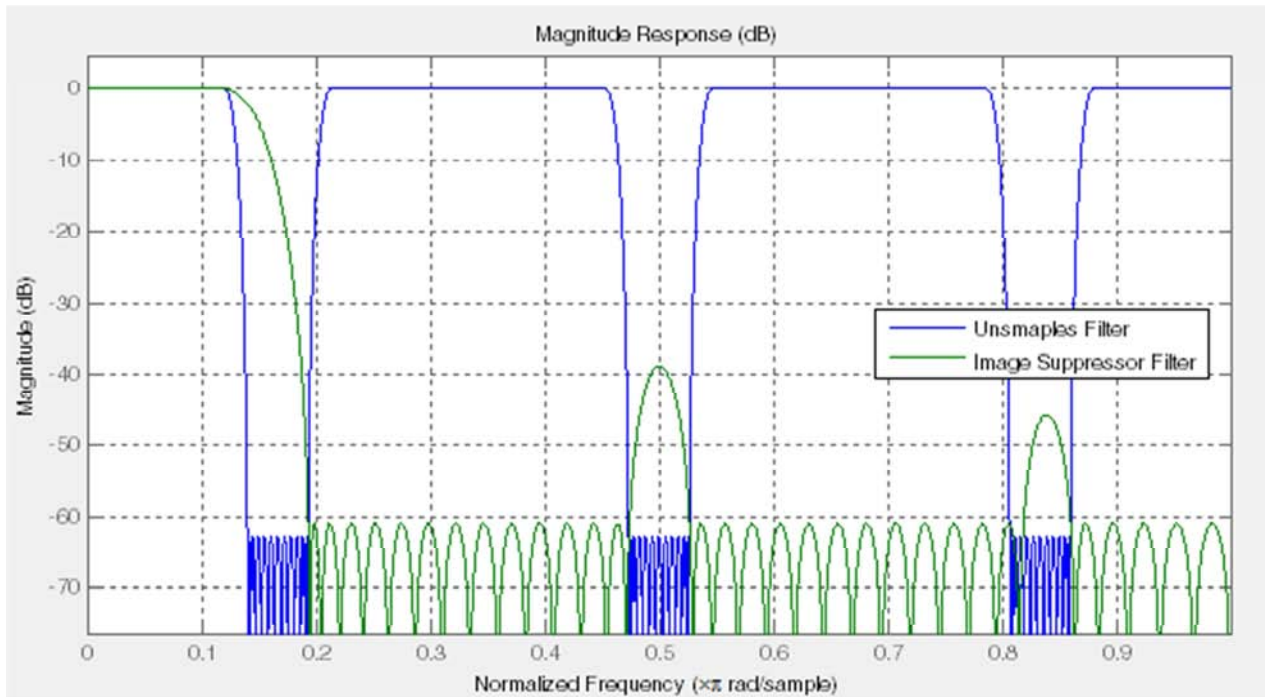


Figure 3. Screenshot of Magnitude Response for Unsmaples and Image Suppressor Filter.

The screenshot of magnitude response for unsampled and image suppressor filter is illustrated in Figure 3. This figure gives the very low transition width after sampling the unsampled filter condition. The normalized frequency for passband condition is approximately $0.3 \times \pi$ rad/sample. It is the acceptable range for IFIR filter design analysis.

5.2. Step Response for Unsmaples and Image Suppressor Filter

Similarly, the screenshot of step response for unsampled and image suppressor filter is shown in Figure 4. The steady state condition is around 75 samples after analyzing the IFIR lowpass filter design. It is very close to good performance of filter evaluation.

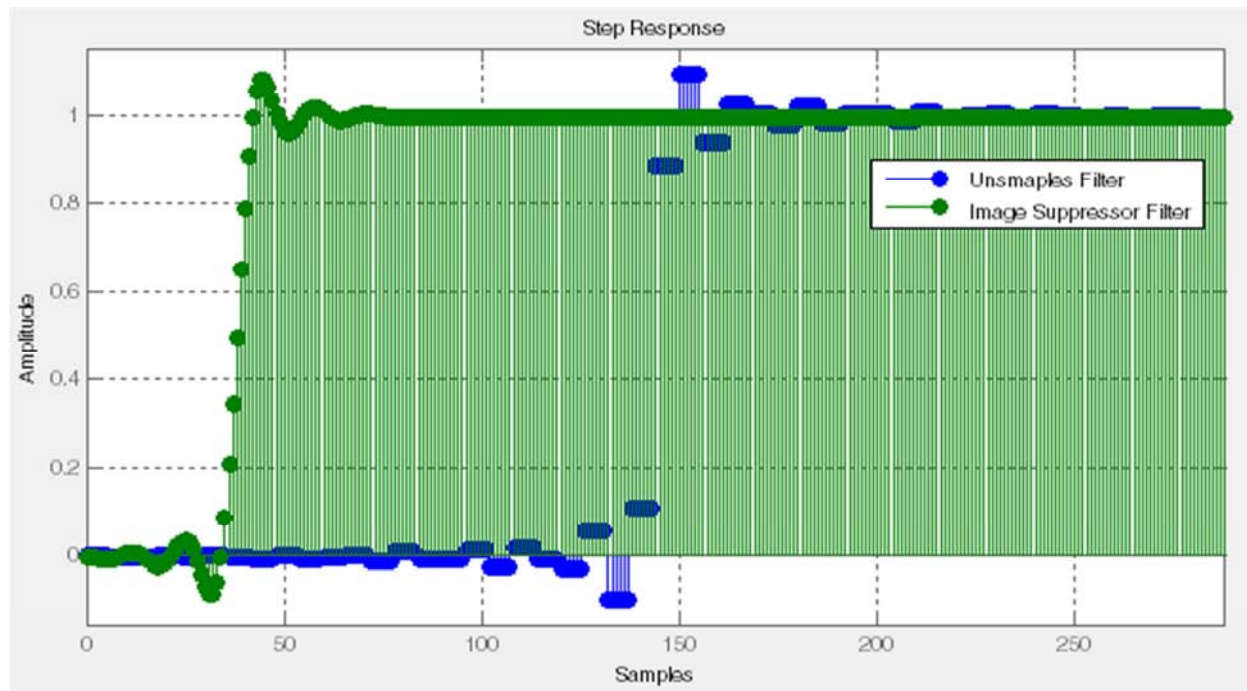


Figure 4. Screenshot of Step Response for Unsmaples and Image Suppressor Filter.

5.3. Simulation Result of Magnitude and Phase Response Comparison

The screenshot of magnitude and phase responses for unsampled and image suppressor filter is mentioned in Figure 5. The phase response for unsampled filter is approximately -326.6314 radians and image suppressor filter is -4.658 radians respectively due to the increment of samples in filter analysis. These responses give the satisfactory results for IFIR lowpass filter design analysis for high data rate situation in satellite communication system.

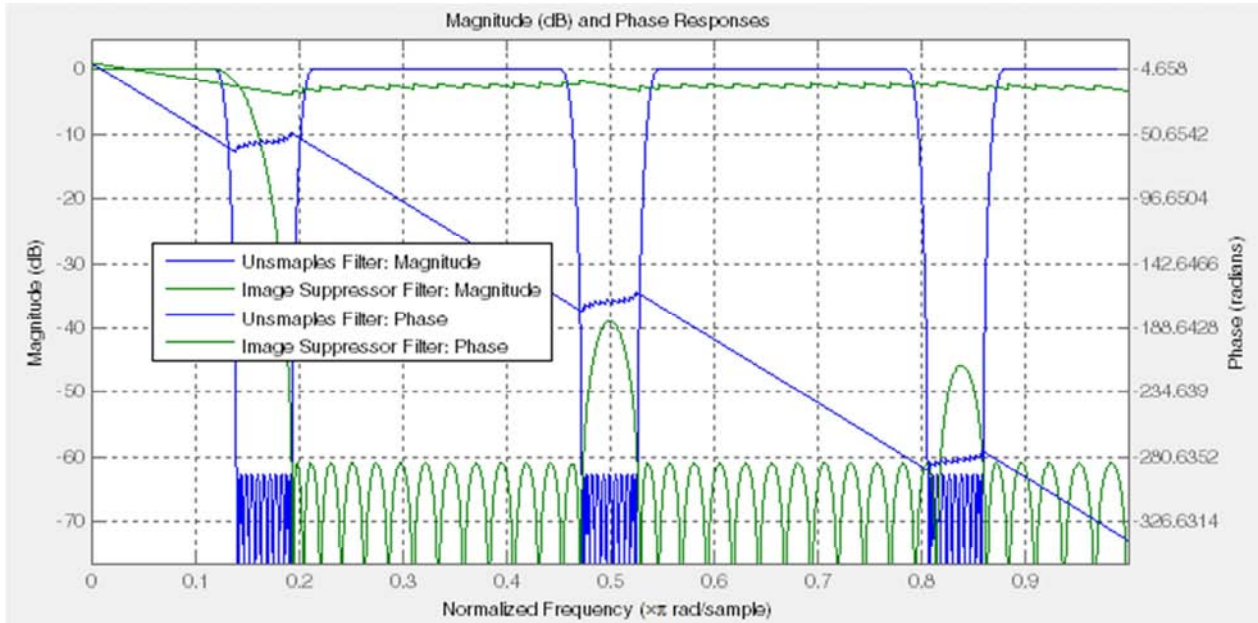


Figure 5. Screenshot of Magnitude and Phase Responses for Unsampled and Image Suppressor Filter.

5.4. Simulation Result of Impulse Response

The screenshot of impulse response for unsampled and image suppressor filter is shown in Figure 6. It is very convenient response for high data rate filter analysis.

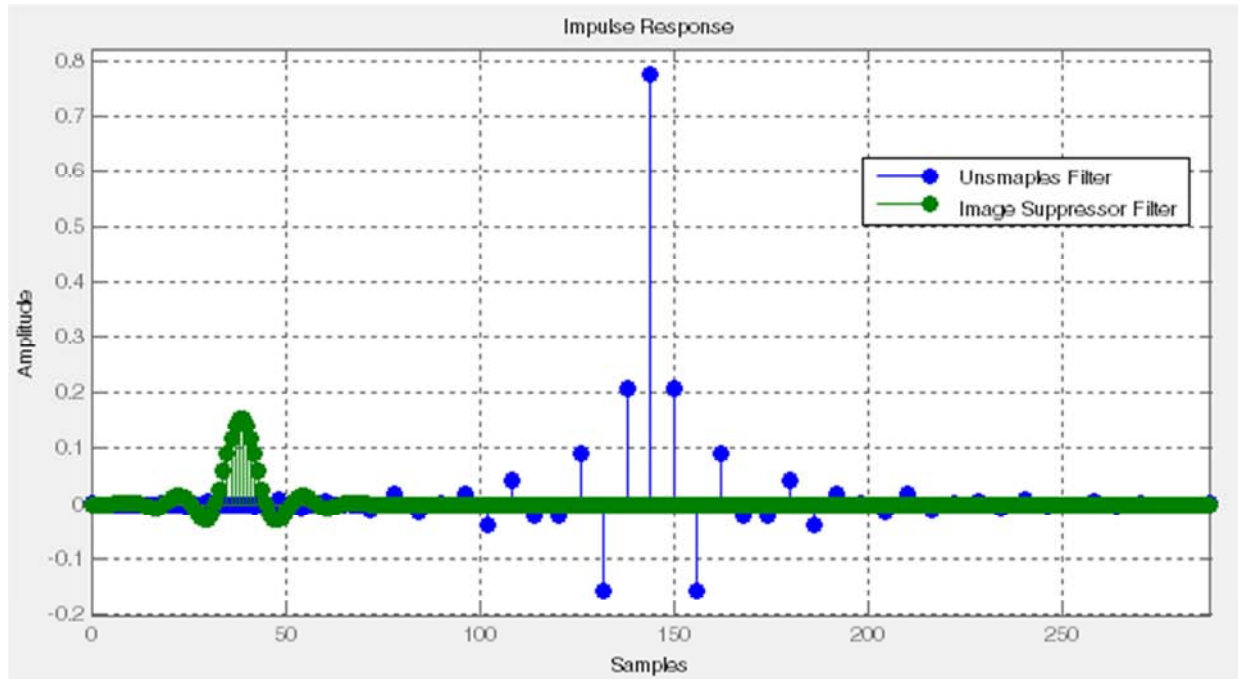


Figure 6. Impulse Response for Unsampled and Image Suppressor Filter.

5.5. Simulation Results for IFIR Filter Design

The second one is the analysis of IFIR filter design for high data rate condition.

5.6. Magnitude Response for IFIR Filter

The screenshot of magnitude response for IFIR lowpass filter is illustrated in Figure 7. This figure also provides the very stumpy transition width for lowpass filter condition. The normalized frequency for passband condition is approximately $0.03 \times \pi$ rad/sample. It is the acceptable range for IFIR filter design analysis.

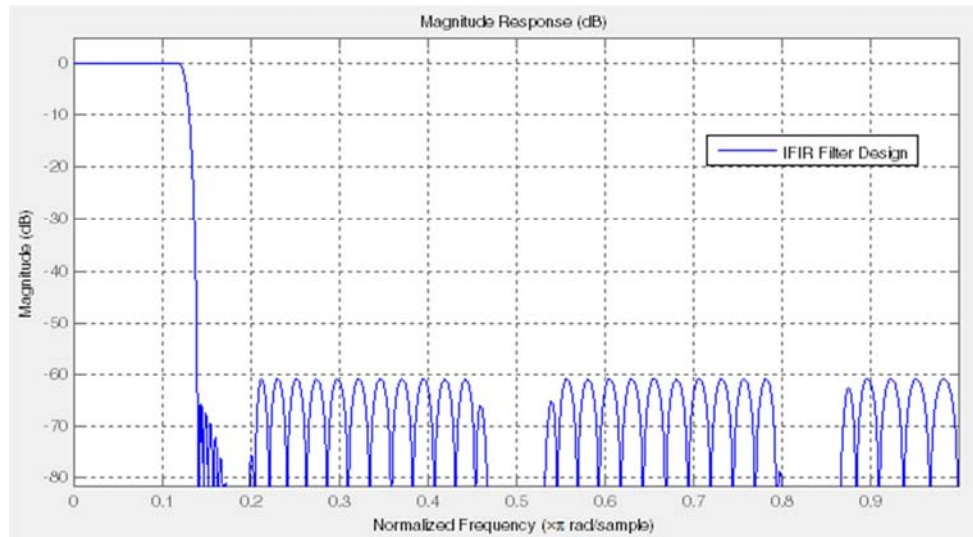


Figure 7. Screenshot of Magnitude Response for IFIR Filter.

5.7. Step Response for IFIR Filter

Likewise, the screenshot of step response for IFIR lowpass filter is shown in Figure 8. The steady state condition is around 300 samples after analyzing the IFIR low pass filter design. It is very secure to superior performance of IFIR lowpass filter evaluation.

5.8. Magnitude and Phase Responses for IFIR Filter

The screenshot of magnitude and phase responses for IFIR lowpass filter is mentioned in Figure 9. The phase response for IFIR lowpass filter is -370.5396 radians respectively due to the increment of samples in filter analysis. These responses offer the reasonable results for IFIR lowpass filter design analysis for high data rate situation in satellite communication system.

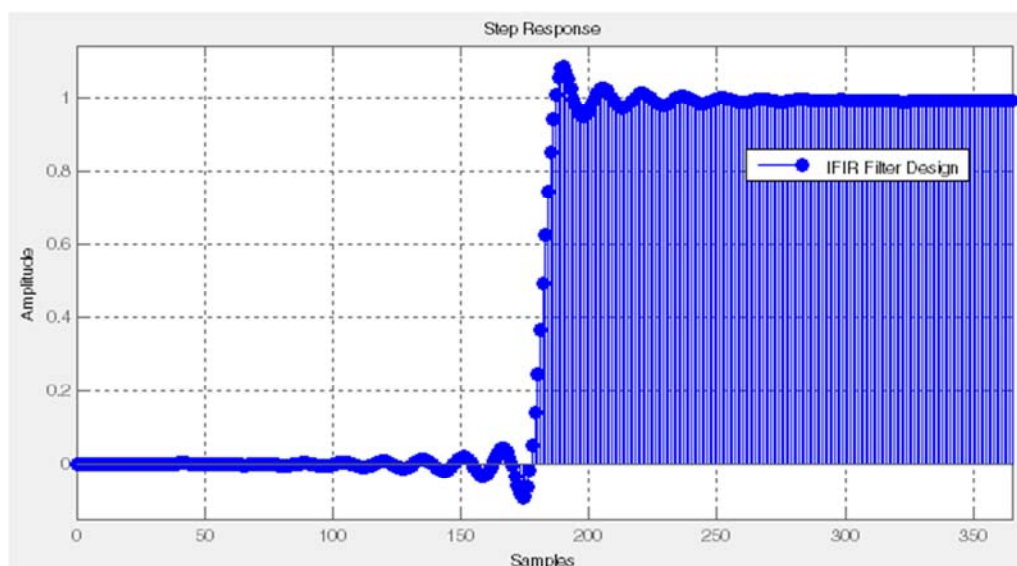


Figure 8. Screenshot of Step Response for IFIR Filter.

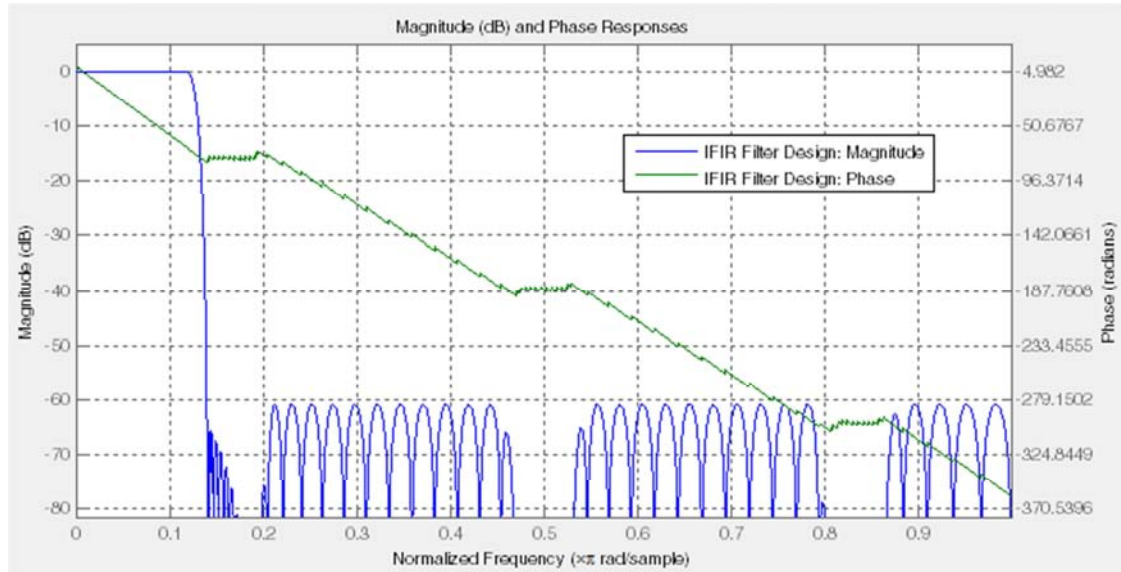


Figure 9. Screenshot of Magnitude and Phase Responses for IFIR Filter.

5.9. Impulse Response for IFIR Filter

The screenshot of impulse response for IFIR lowpass filter is shown in Figure 10. It is very expedient response for high data rate filter analysis.

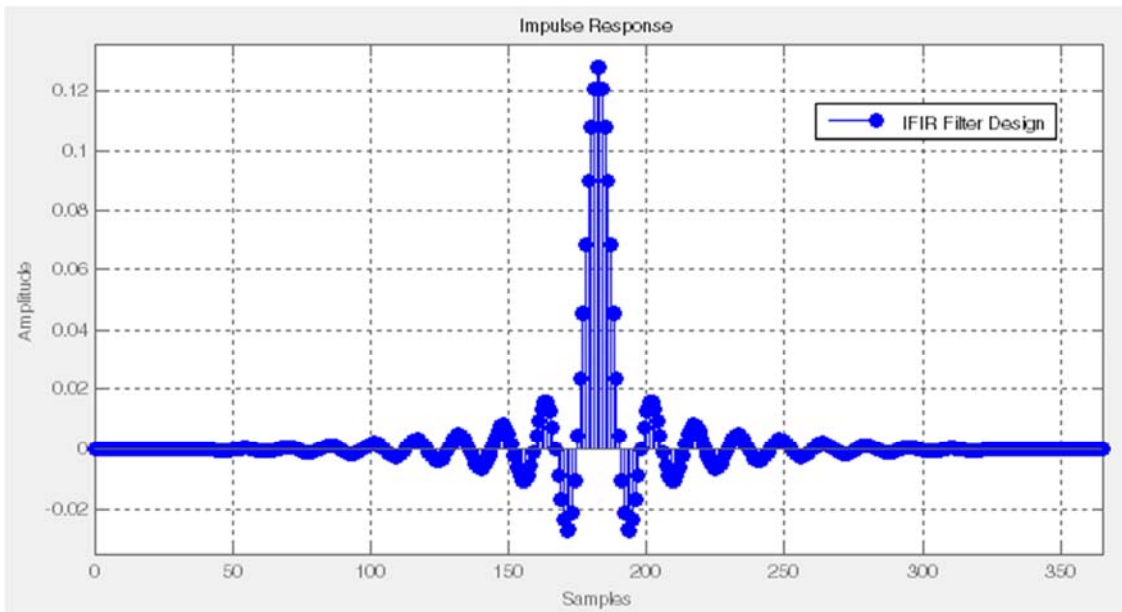


Figure 10. Screenshot of Impulse Response for IFIR Filter.

6. Conclusion

A Digital IFIR filter is designed, simulated & implemented in MATLAB. The designed filter can be used in DSP based Costas loop demodulator for enhancing its frequency of operation & stability. Result shows that operating frequency of IFIR filter is more than 5 times of that of IIR filter and when it is used in demodulator then the system operating frequency increase by 3 times to that of corresponding IIR filter based demodulator. Hardware side also IFIR filter uses less multiplier. The designed IFIR filter is free from limit

cycle problem, hence highly stable in noisy input signal. The number of taps is less than conventional FIR filter and by using the symmetric property the hardware is reduced further. As the entire design is written in VHDL language, therefore can be targeted to hardware developments.

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