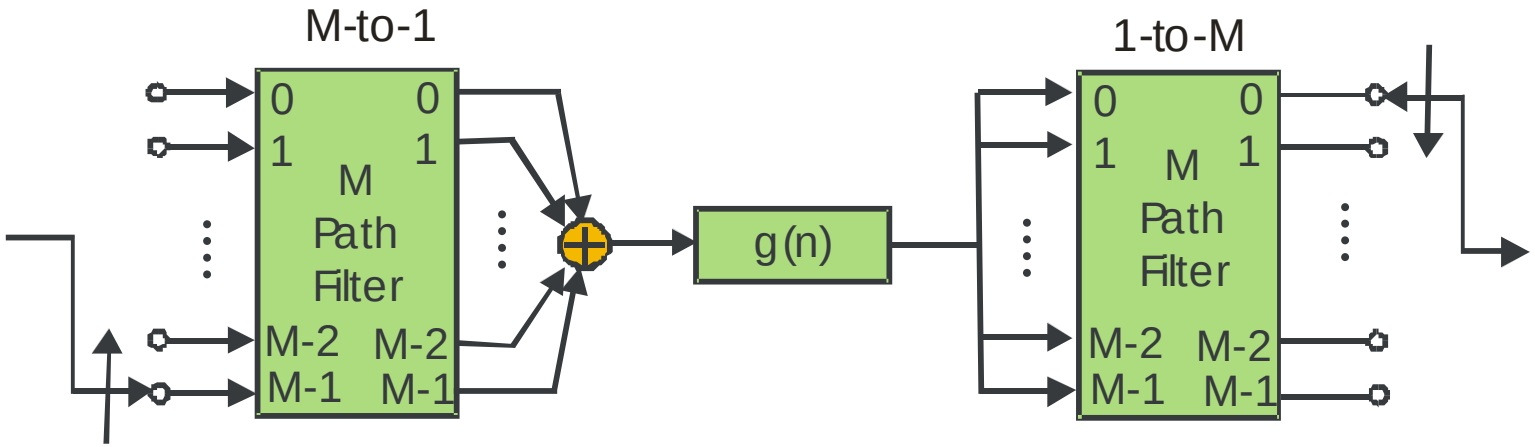
Green Filters

Cascade
Polyphase M-to-1 Down Sample Filter,
Inner Filter,
and Polyphase 1-to-M Up Sample Filter

fred harris



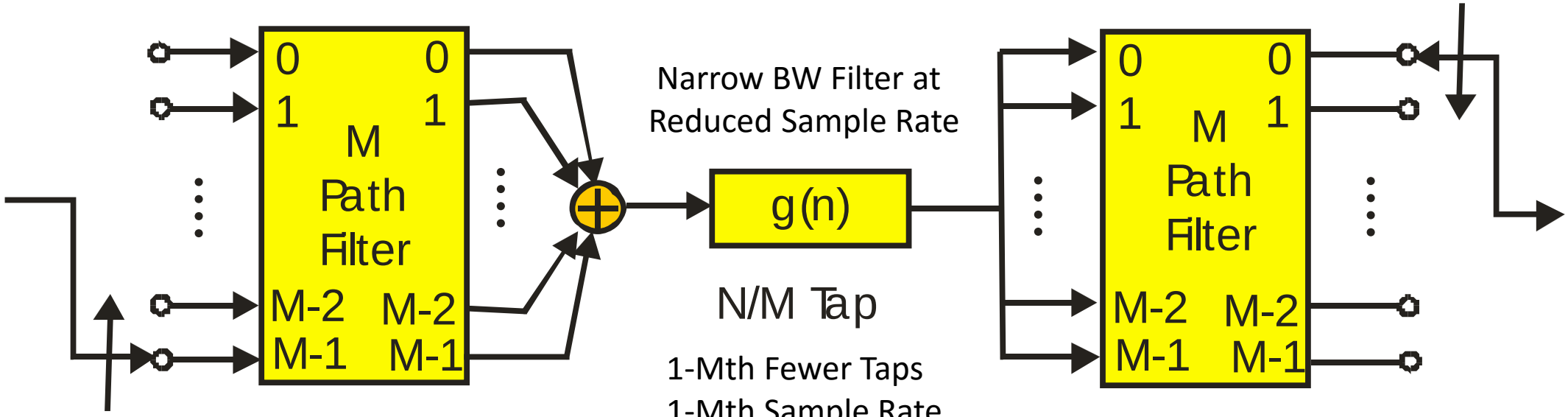
Narrow Bandwidth Filter with Large Ratio Sample Rate to Bandwidth

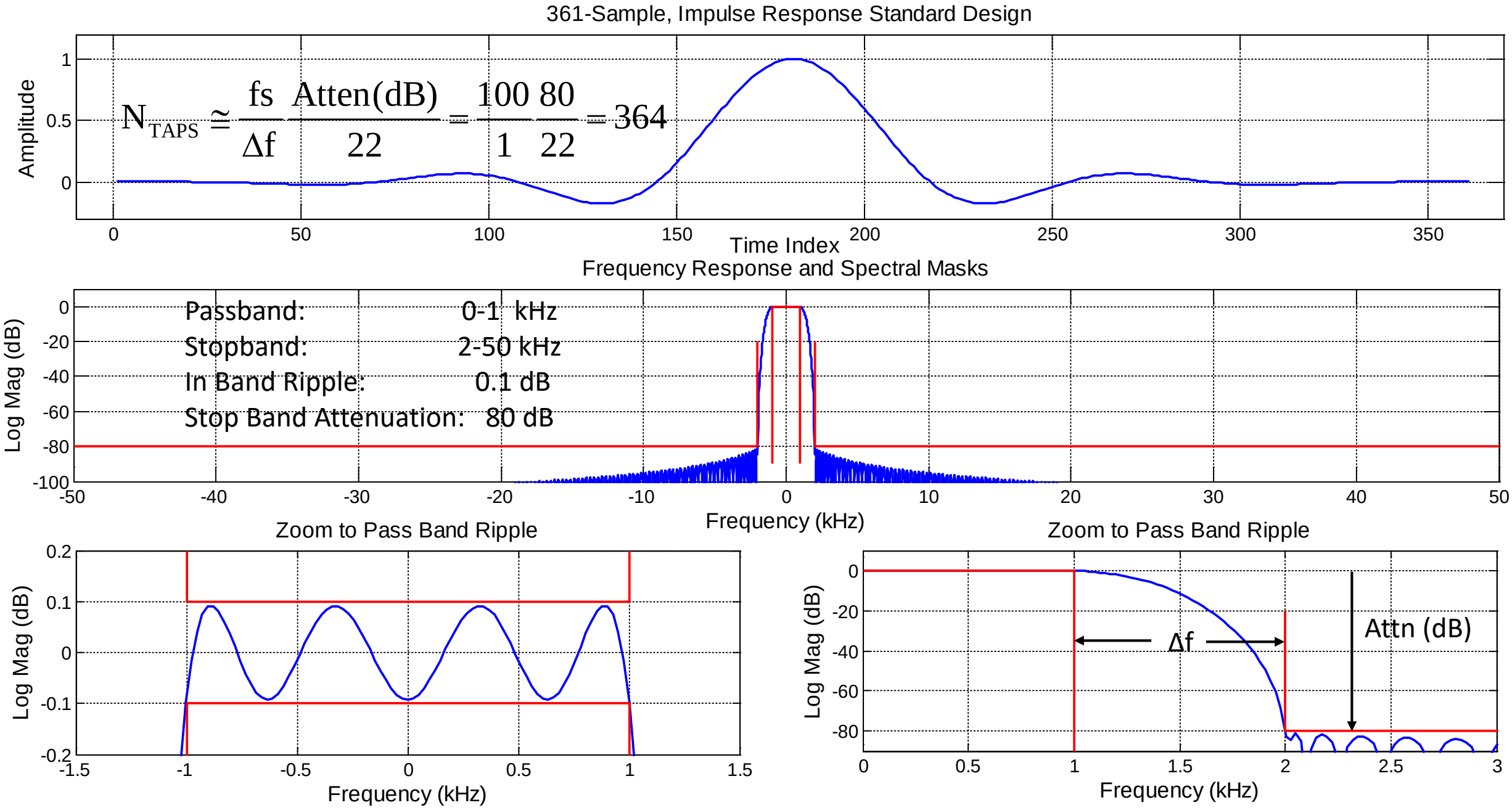
Many Taps

$$N_{TAPS} \cong \frac{fs}{\Delta f}\frac{Atten(dB)}{22}$$

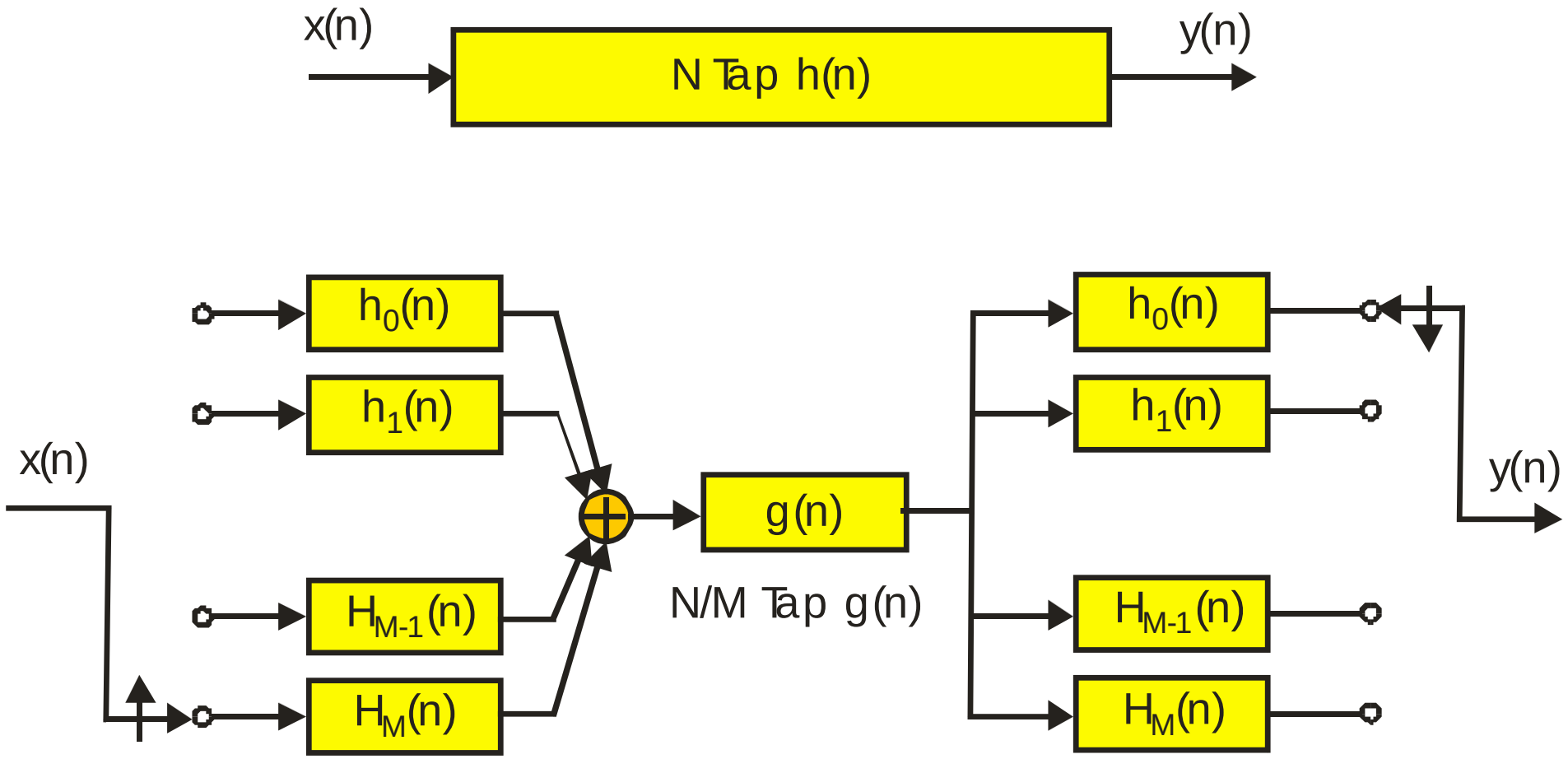
Reduce Bandwidth and
Reduce Sample Rate M-to-1

Increase Sample Rate 1-to-M

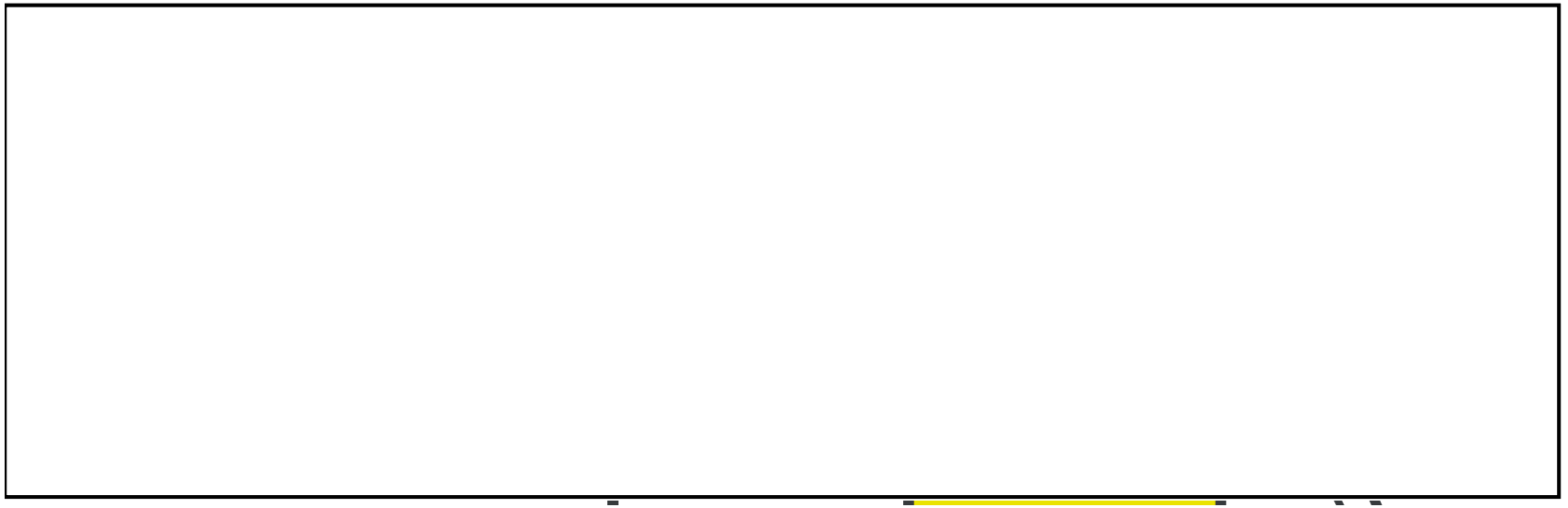


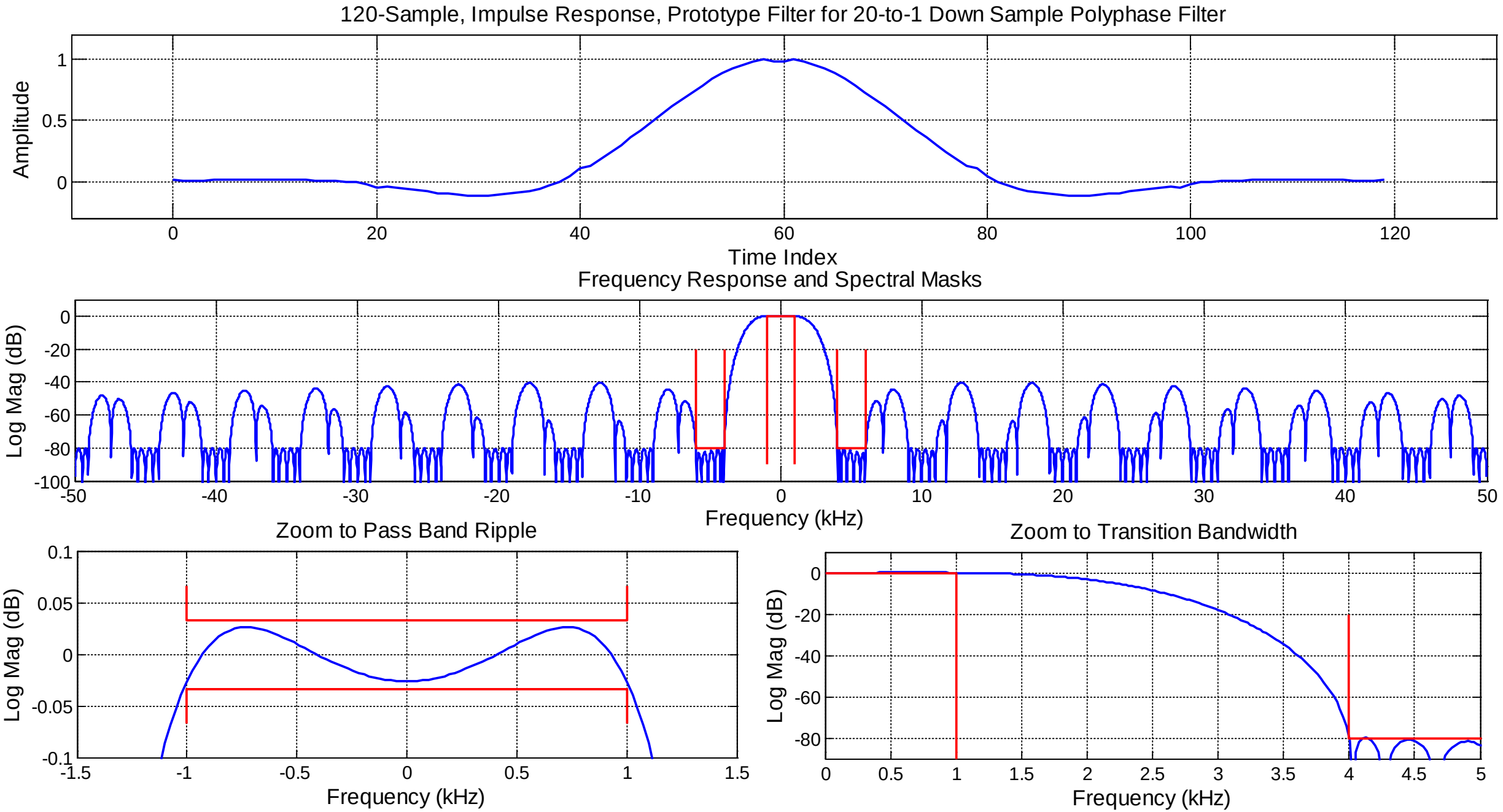

361-Sample, Impulse Response Standard Design
Amplitude
Time Index
$N_{TAPS} \cong \frac{fs}{\Delta f}\frac{Atten(dB)}{22} = \frac{100}{1}\frac{80}{22} = 364$
Frequency Response and Spectral Masks
Passband: 0-1 kHz
Stopband: 2-50 kHz
In Band Ripple: 0.1 dB
Stop Band Attenuation: 80 dB
Log Mag (dB)
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
Frequency (kHz)
Zoom to Pass Band Ripple
Δf
Attn (dB)
Log Mag (dB)
Frequency (kHz)

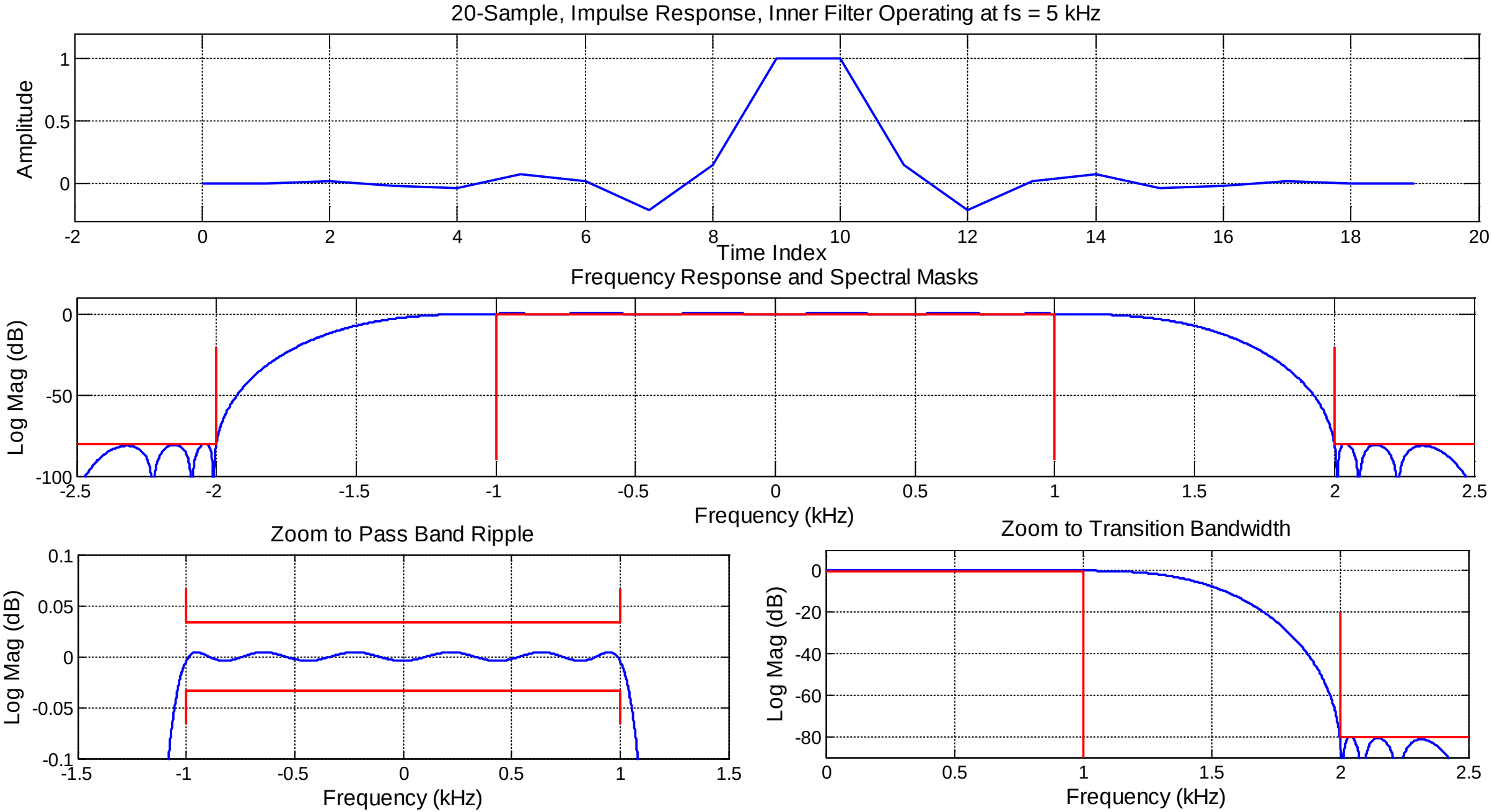
Cascade M-to-1 Down Sampling Filter, Inner Filter, and 1-to-M Up Sampling Filter

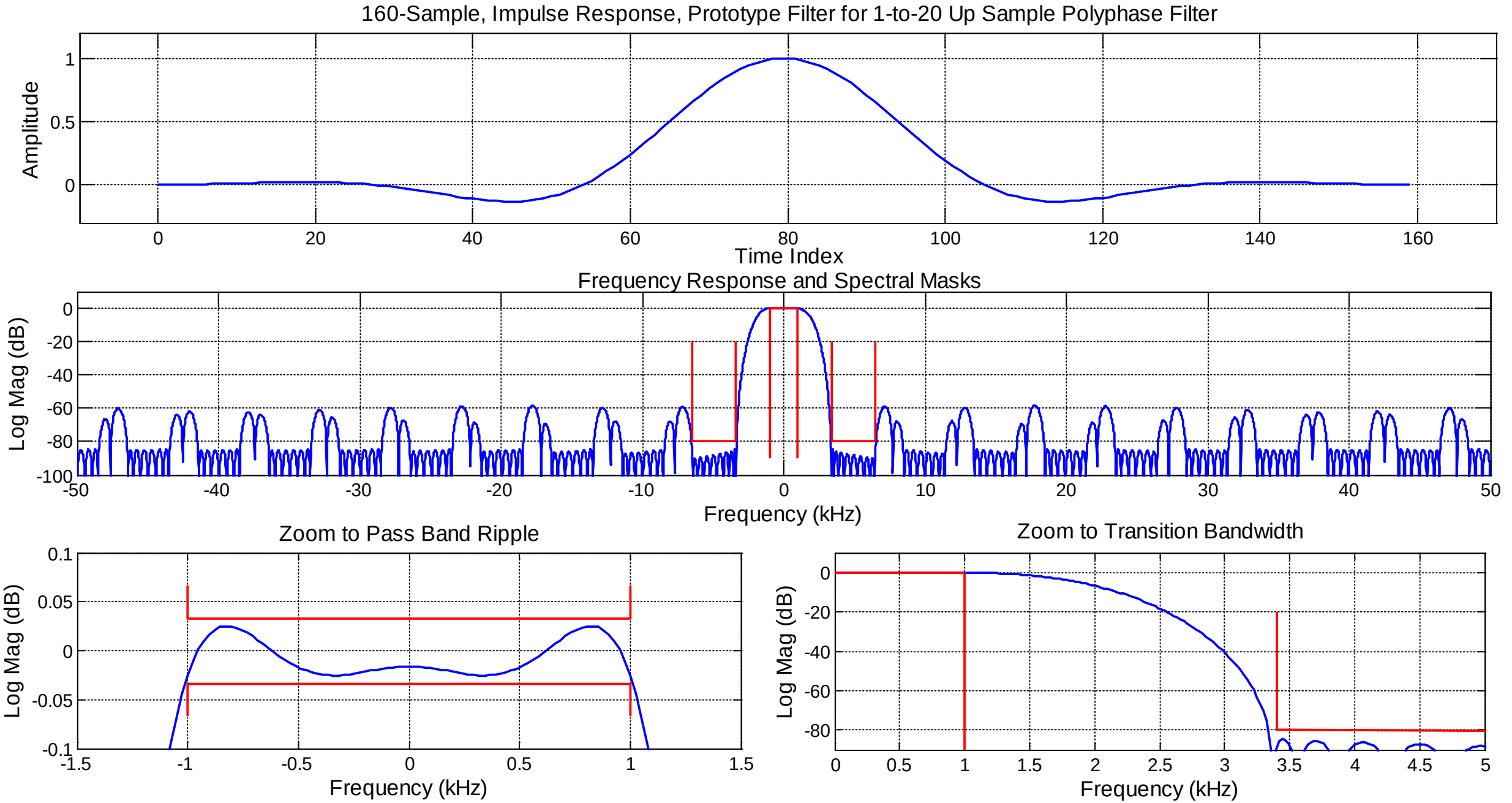


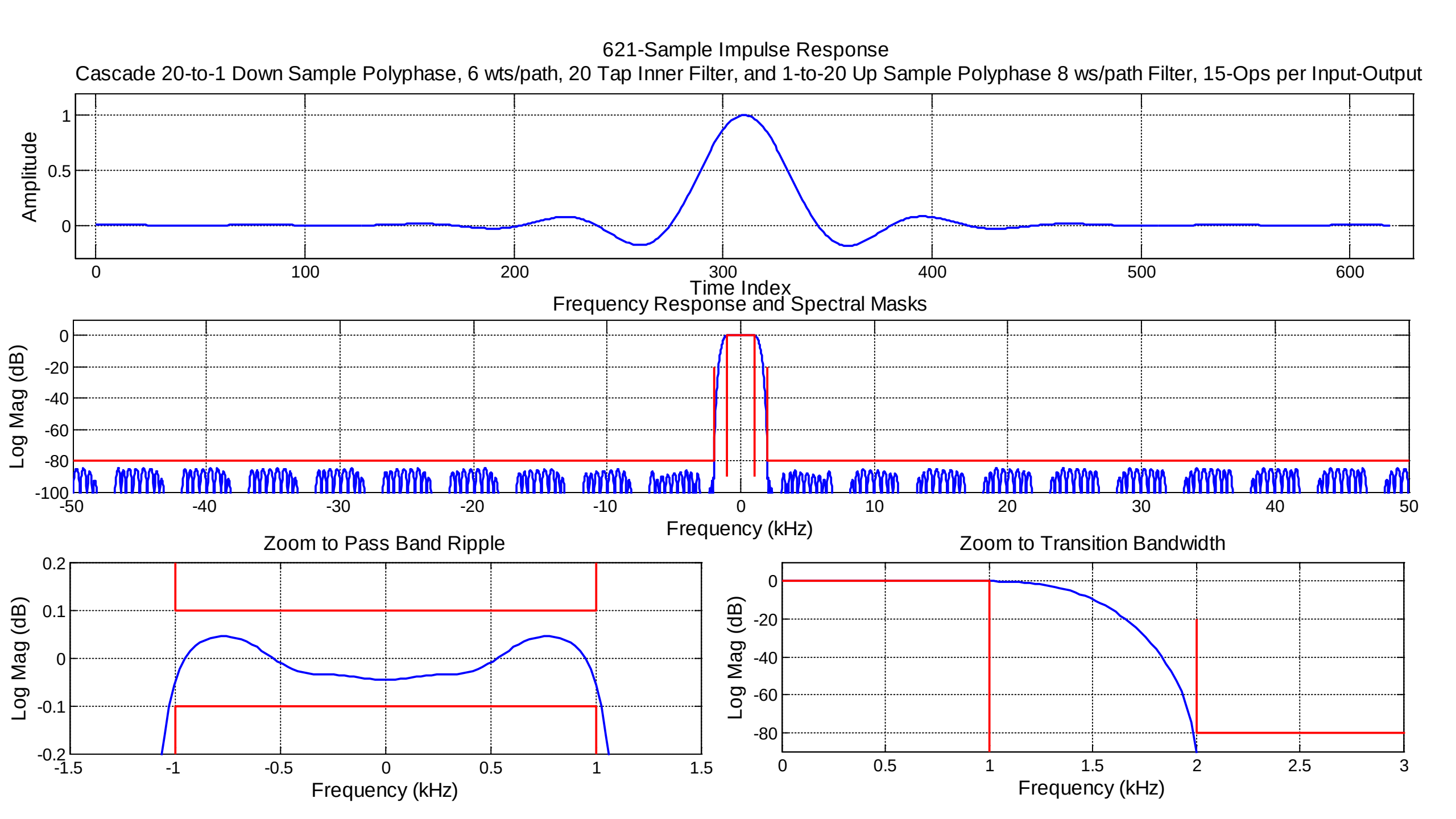
In Particular, Examine a
20 Path Cascade Filter



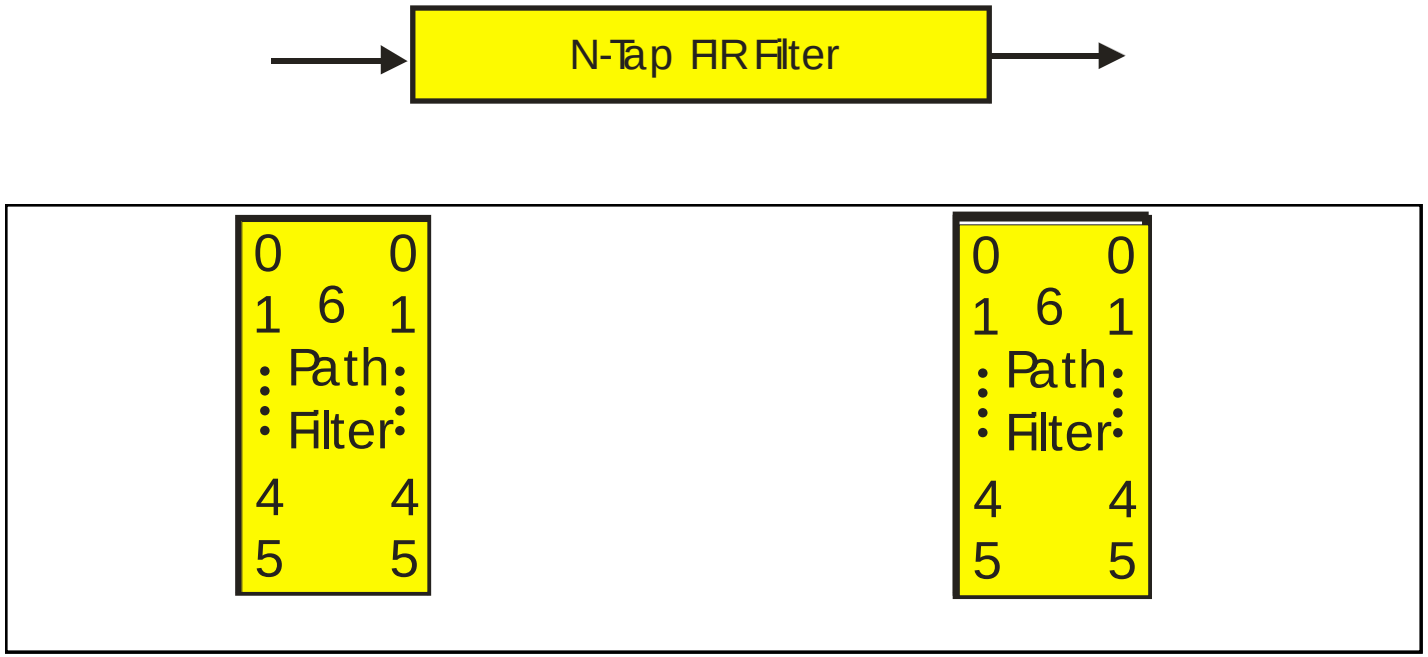

120-Sample, Impulse Response, Prototype Filter for 20-to-1 Down Sample Polyphase Filter
Amplitude
Time Index
Frequency Response and Spectral Masks
Log Mag (dB)
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
Frequency (kHz)
Zoom to Transition Bandwidth
Log Mag (dB)
Frequency (kHz)

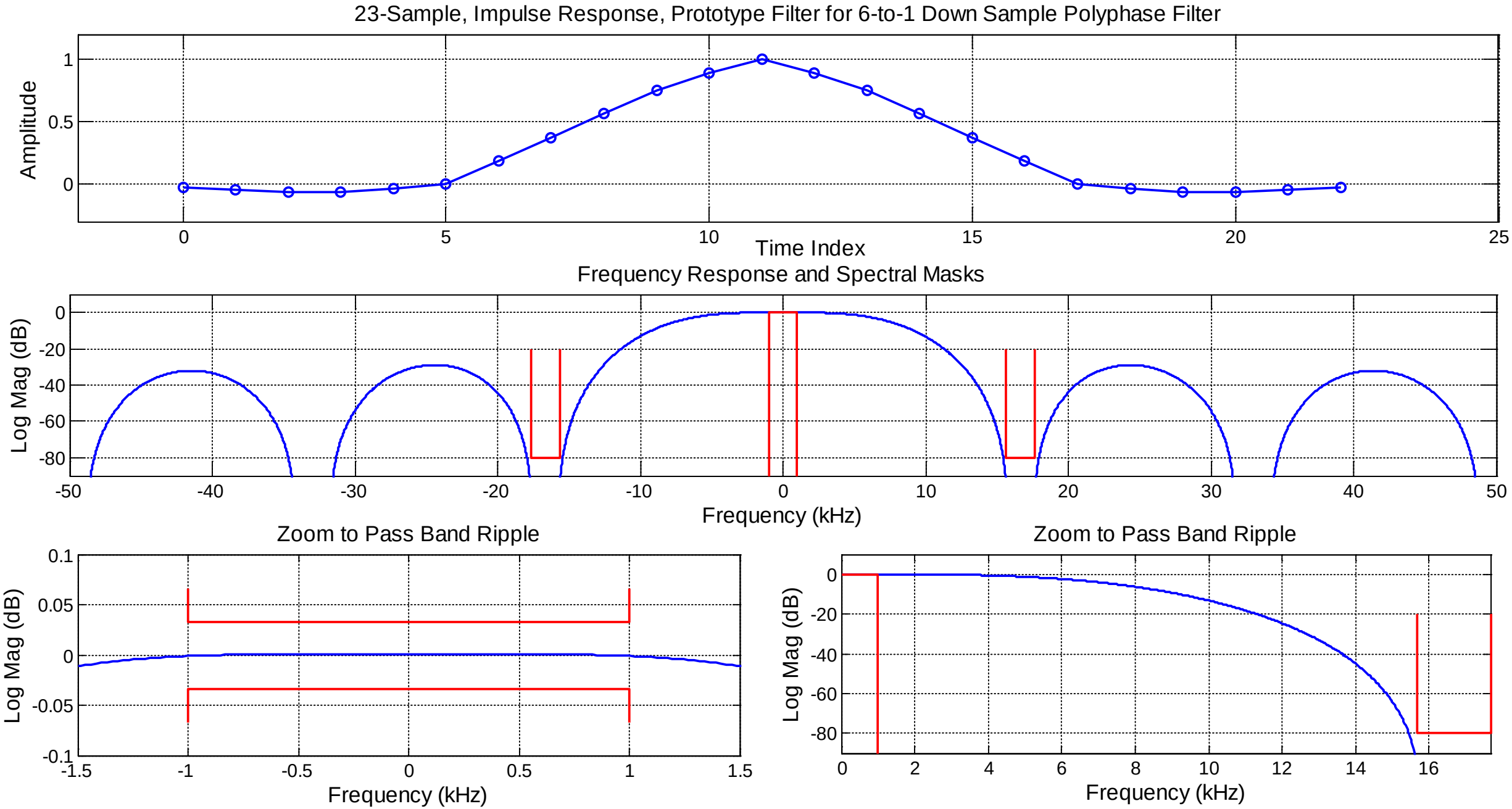

20-Sample, Impulse Response, Inner Filter Operating at fs = 5 kHz
Amplitude
Time Index
Frequency Response and Spectral Masks
Log Mag (dB)
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
Frequency (kHz)
Zoom to Transition Bandwidth
Log Mag (dB)
Frequency (kHz)

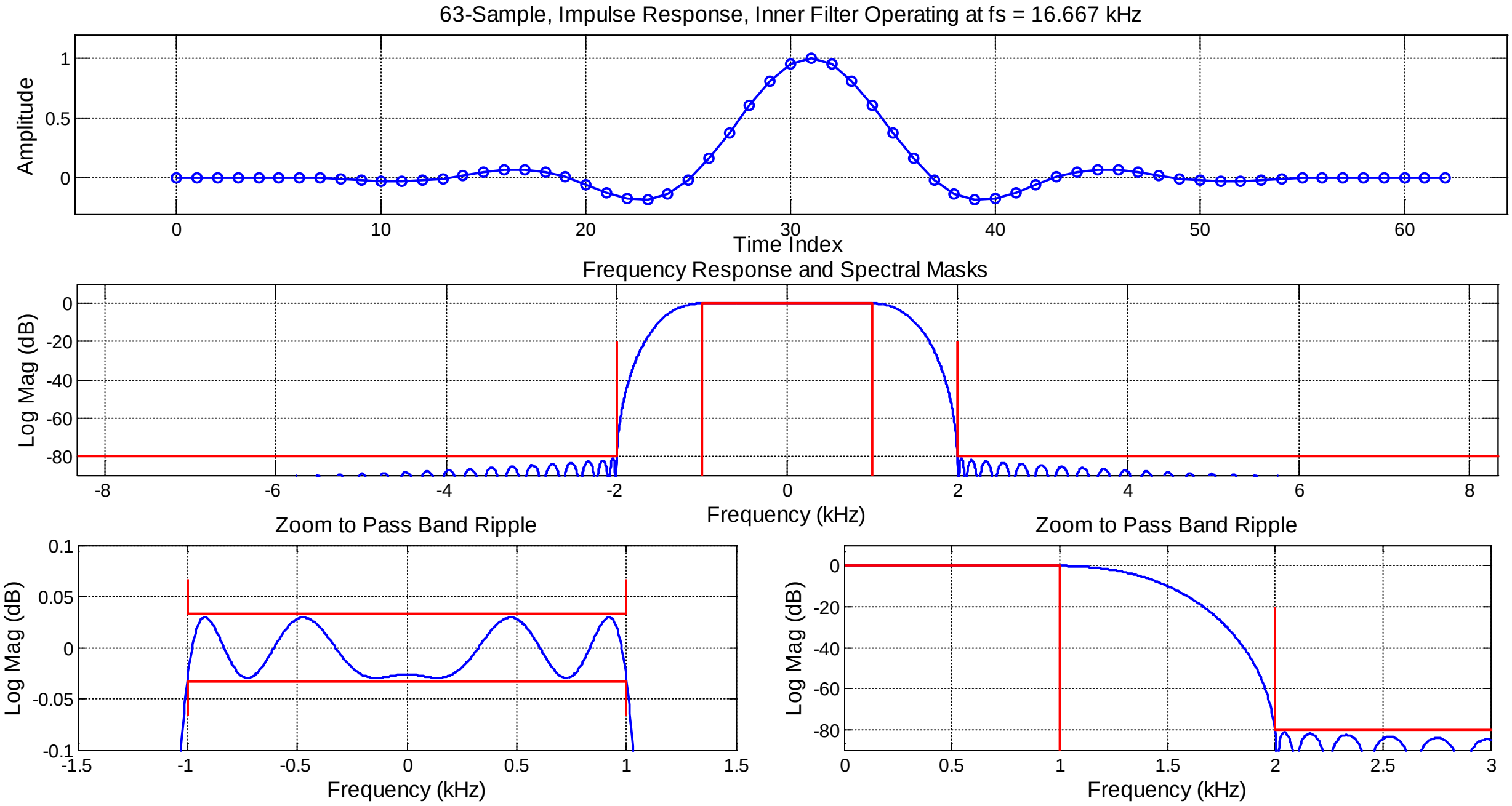

160-Sample, Impulse Response, Prototype Filter for 1-to-20 Up Sample Polyphase Filter
Amplitude
Time Index
Frequency Response and Spectral Masks
Log Mag (dB)
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
Frequency (kHz)
Zoom to Transition Bandwidth
Log Mag (dB)
Frequency (kHz)

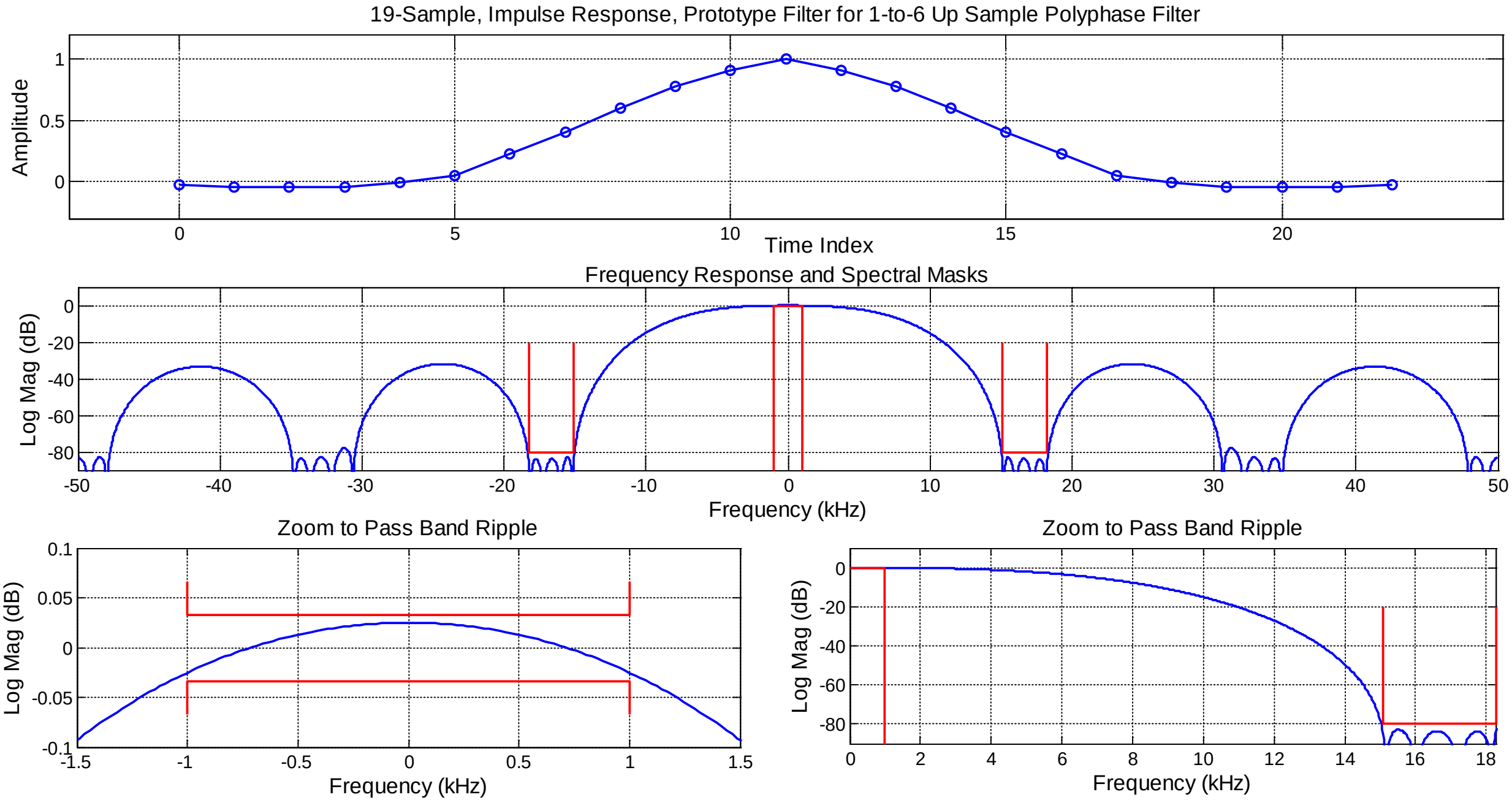

621-Sample Impulse Response
Cascade 20-to-1 Down Sample Polyphase, 6 wts/path, 20 Tap Inner Filter, and 1-to-20 Up Sample Polyphase 8 ws/path Filter, 15-Ops per Input-Output
Amplitude
Time Index
Frequency Response and Spectral Masks
Log Mag (dB)
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
Frequency (kHz)
Zoom to Transition Bandwidth
Log Mag (dB)
Frequency (kHz)

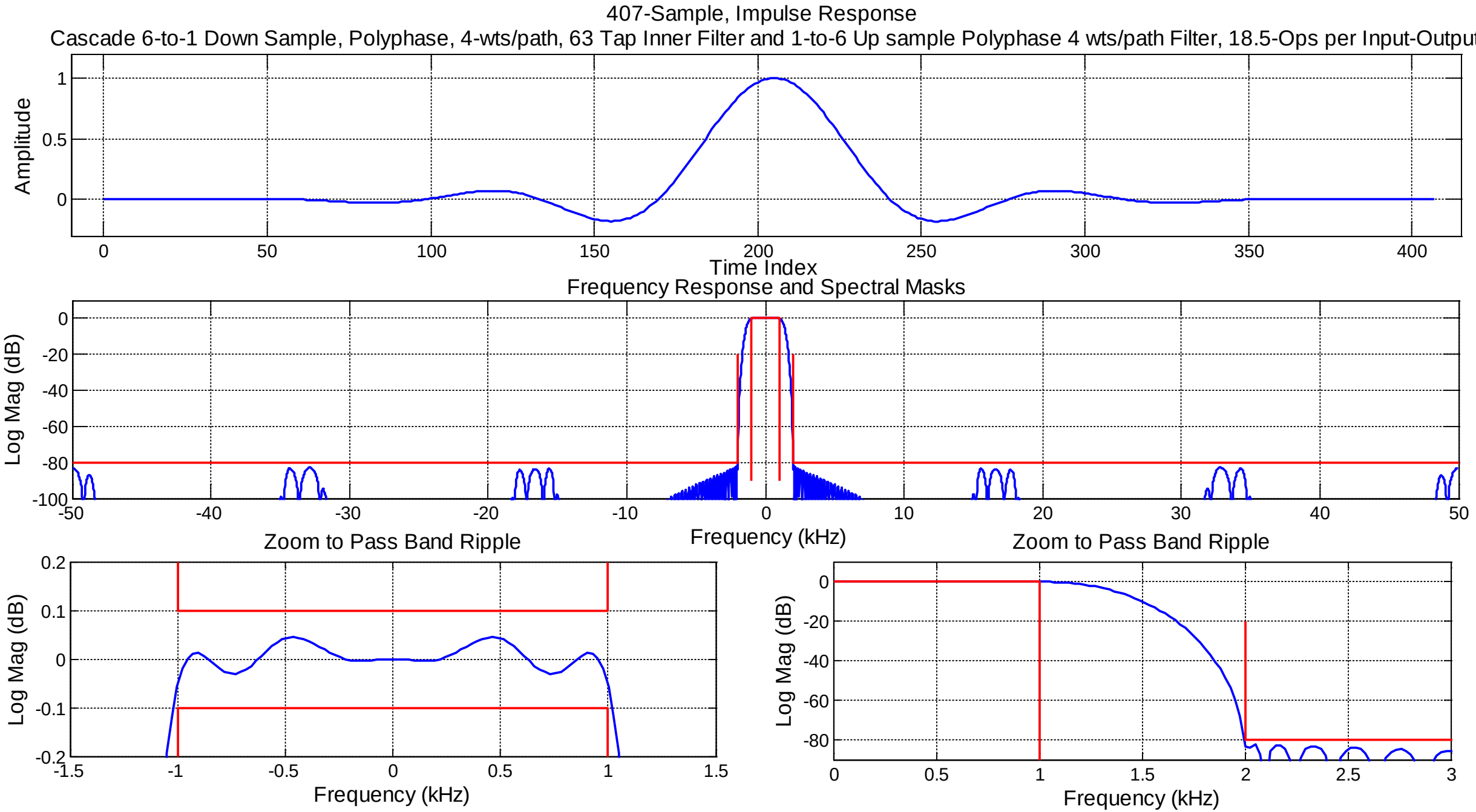
Now Consider a 6 Path Cascade Filter



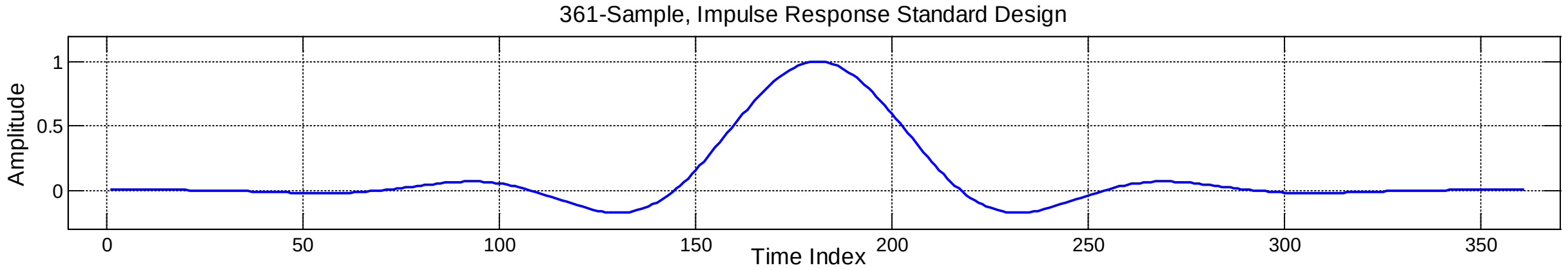

23-Sample, Impulse Response, Prototype Filter for 6-to-1 Down Sample Polyphase Filter
Amplitude
1
0.5
0
0
5
10
15
20
25
Time Index
Frequency Response and Spectral Masks
Log Mag (dB)
0
-20
-40
-60
-80
-50
-40
-30
-20
-10
0
10
20
30
40
50
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
0.1
0.05
0
-0.05
-0.1
-1.5
-1
-0.5
0
0.5
1
1.5
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
0
-20
-40
-60
-80
0
2
4
6
8
10
12
14
16
Frequency (kHz)

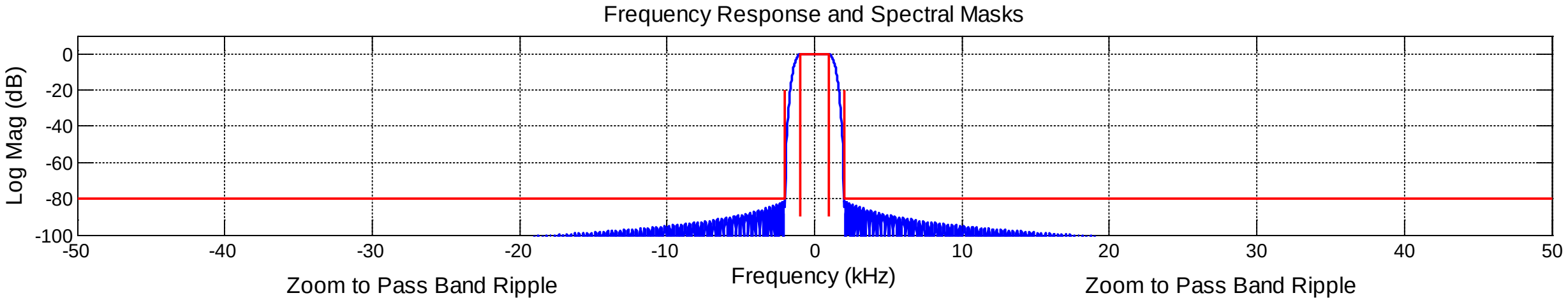

63-Sample, Impulse Response, Inner Filter Operating at fs = 16.667 kHz
Amplitude
Time Index
Frequency Response and Spectral Masks
Log Mag (dB)
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
Frequency (kHz)

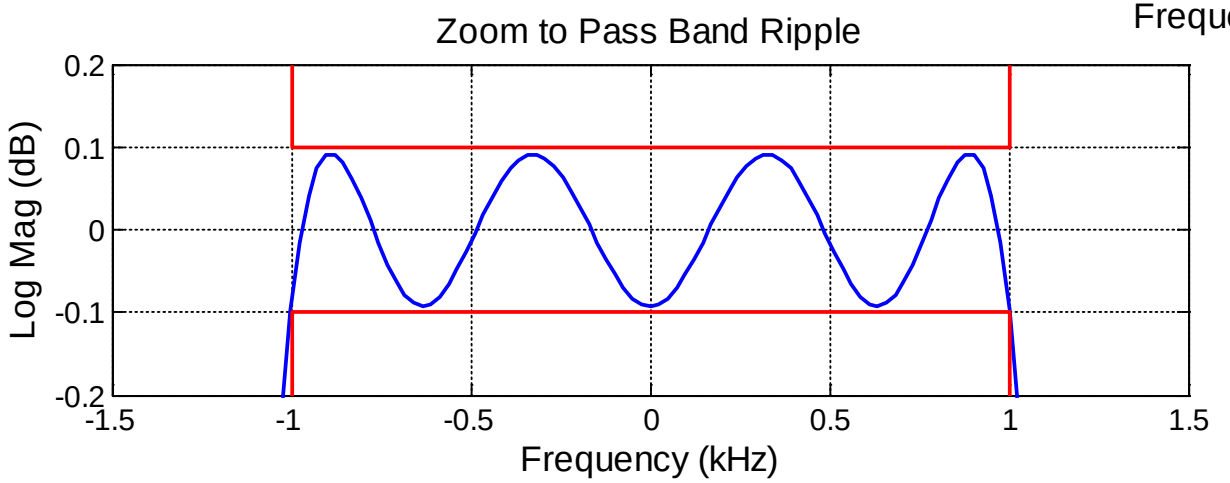

19-Sample, Impulse Response, Prototype Filter for 1-to-6 Up Sample Polyphase Filter
Amplitude
1
0.5
0
0
5
10
15
20
Time Index
Frequency Response and Spectral Masks
Log Mag (dB)
0
-20
-40
-60
-80
-50
-40
-30
-20
-10
0
10
20
30
40
50
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
0.1
0.05
0
-0.05
-0.1
-1.5
-1
-0.5
0
0.5
1
1.5
Frequency (kHz)
Zoom to Pass Band Ripple
Log Mag (dB)
0
-20
-40
-60
-80
0
2
4
6
8
10
12
14
16
18
Frequency (kHz)

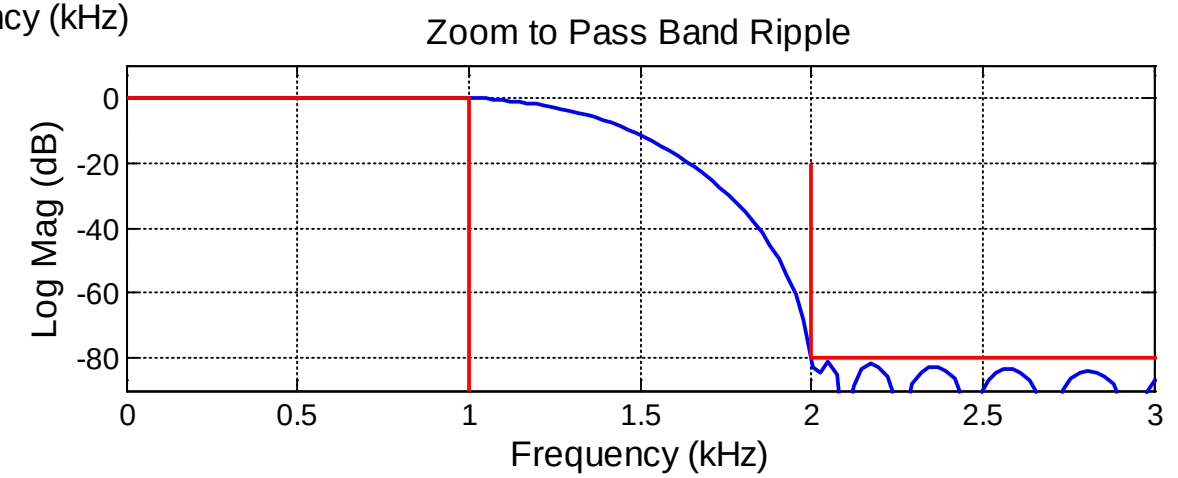

407-Sample, Impulse Response
Cascade 6-to-1 Down Sample, Polyphase, 4-wts/path, 63 Tap Inner Filter and 1-to-6 Up sample Polyphase 4 wts/path Filter, 18.5-Ops per Input-Output
Amplitude
Time Index
Frequency Response and Spectral Masks
Log Mag (dB)
Frequency (kHz)
Zoom to Pass Band Ripple
Zoom to Pass Band Ripple

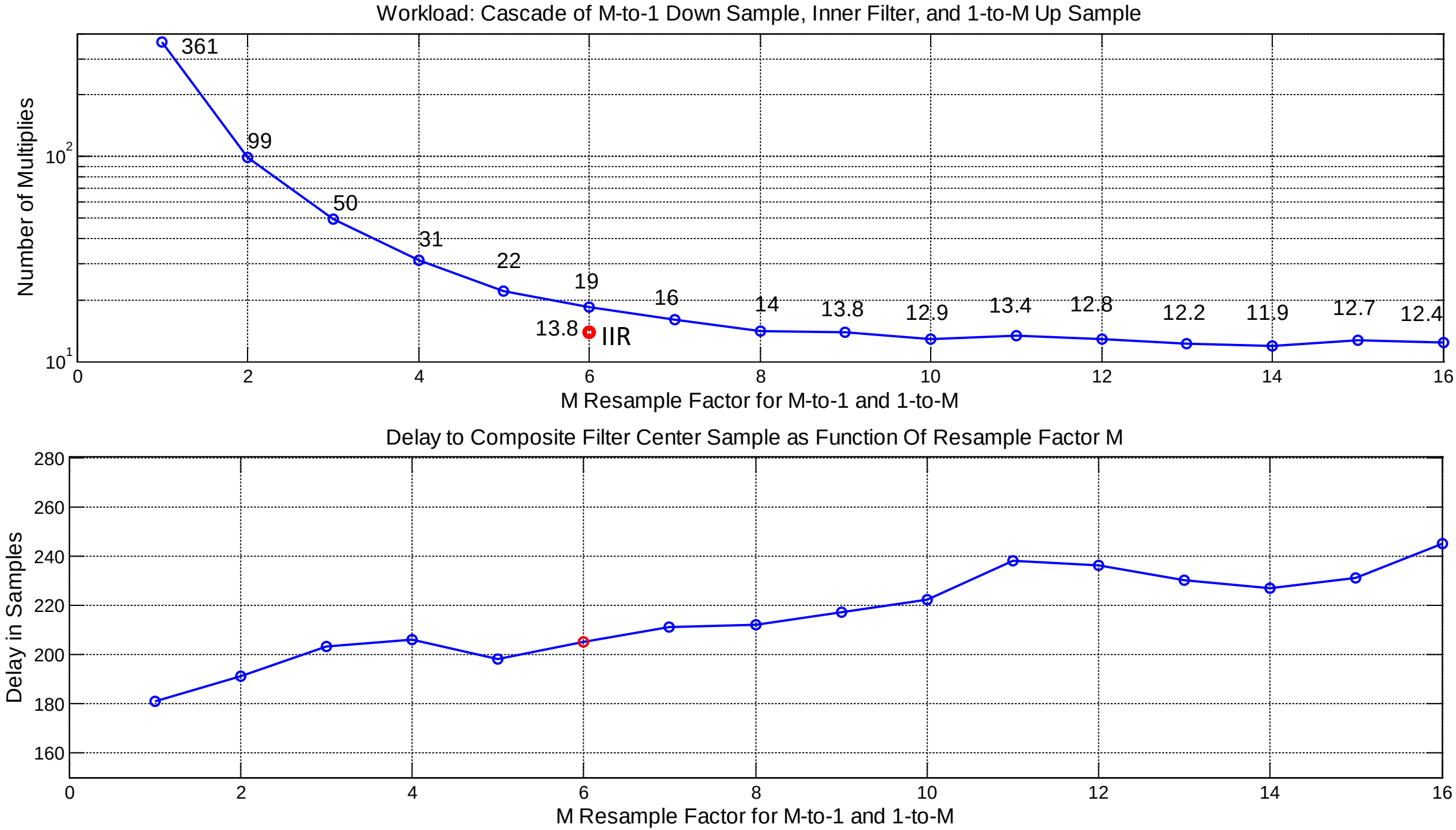
For Reference, Original Design



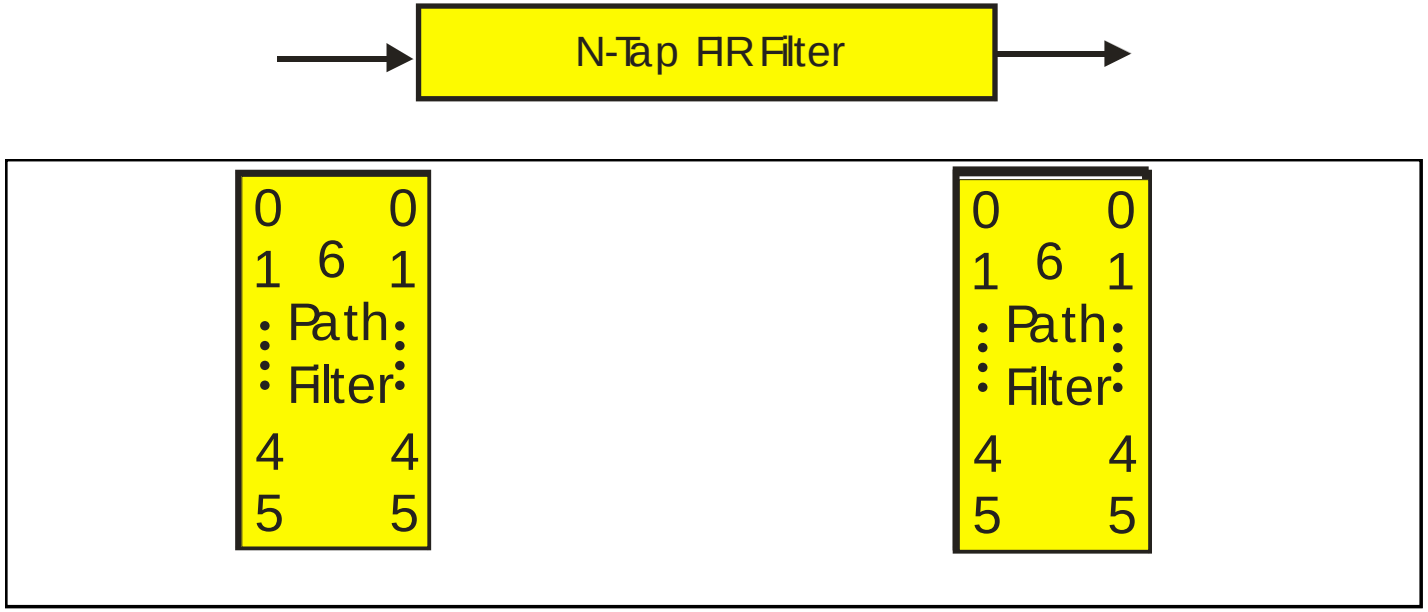




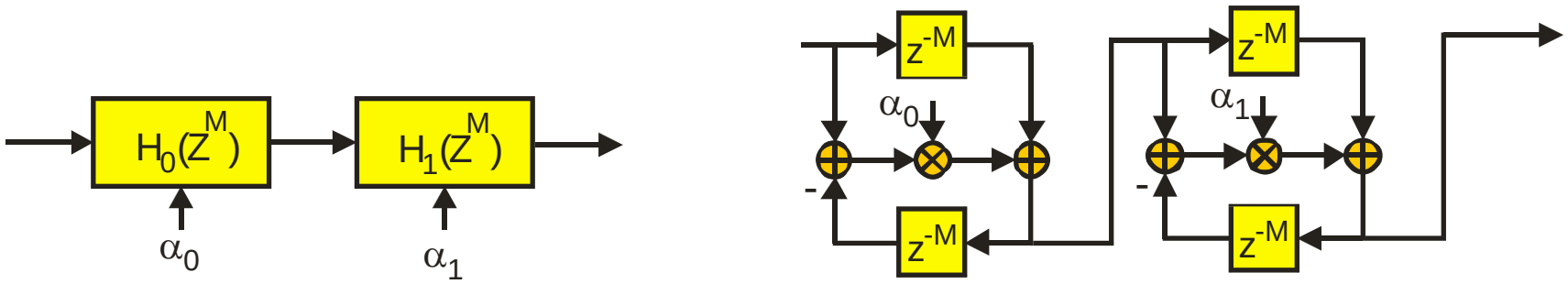


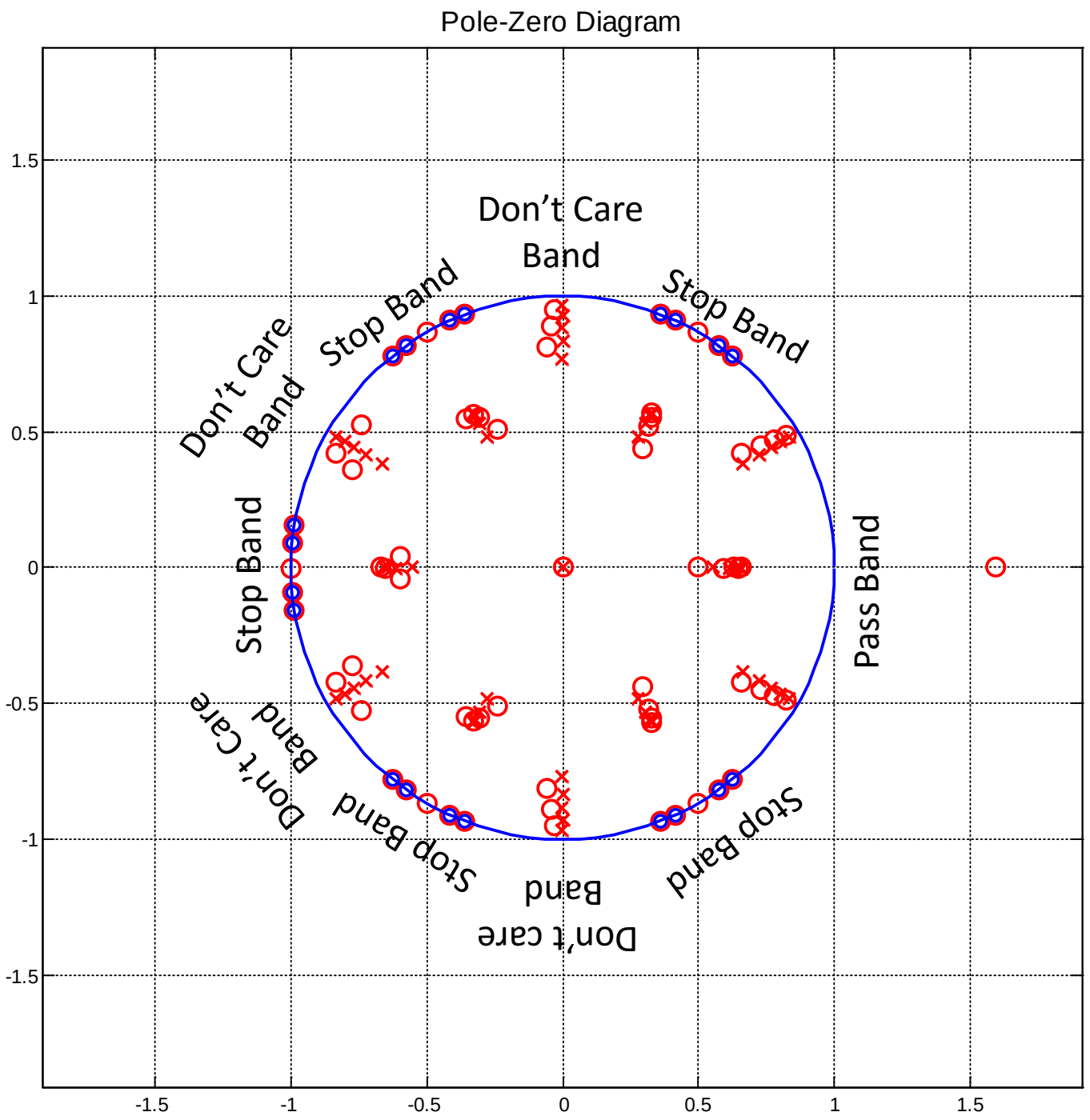

Workload: Cascade of M-to-1 Down Sample, Inner Filter, and 1-to-M Up Sample
Number of Multiplies
10^2
10^1
361
99
50
31
22
19
13.8
IIR
16
14
13.8
12.9
13.4
12.8
12.2
11.9
12.7
12.4
0
2
4
6
8
10
12
14
16
M Resample Factor for M-to-1 and 1-to-M
Delay to Composite Filter Center Sample as Function Of Resample Factor M
Delay in Samples
280
260
240
220
200
180
160
0
2
4
6
8
10
12
14
16
M Resample Factor for M-to-1 and 1-to-M

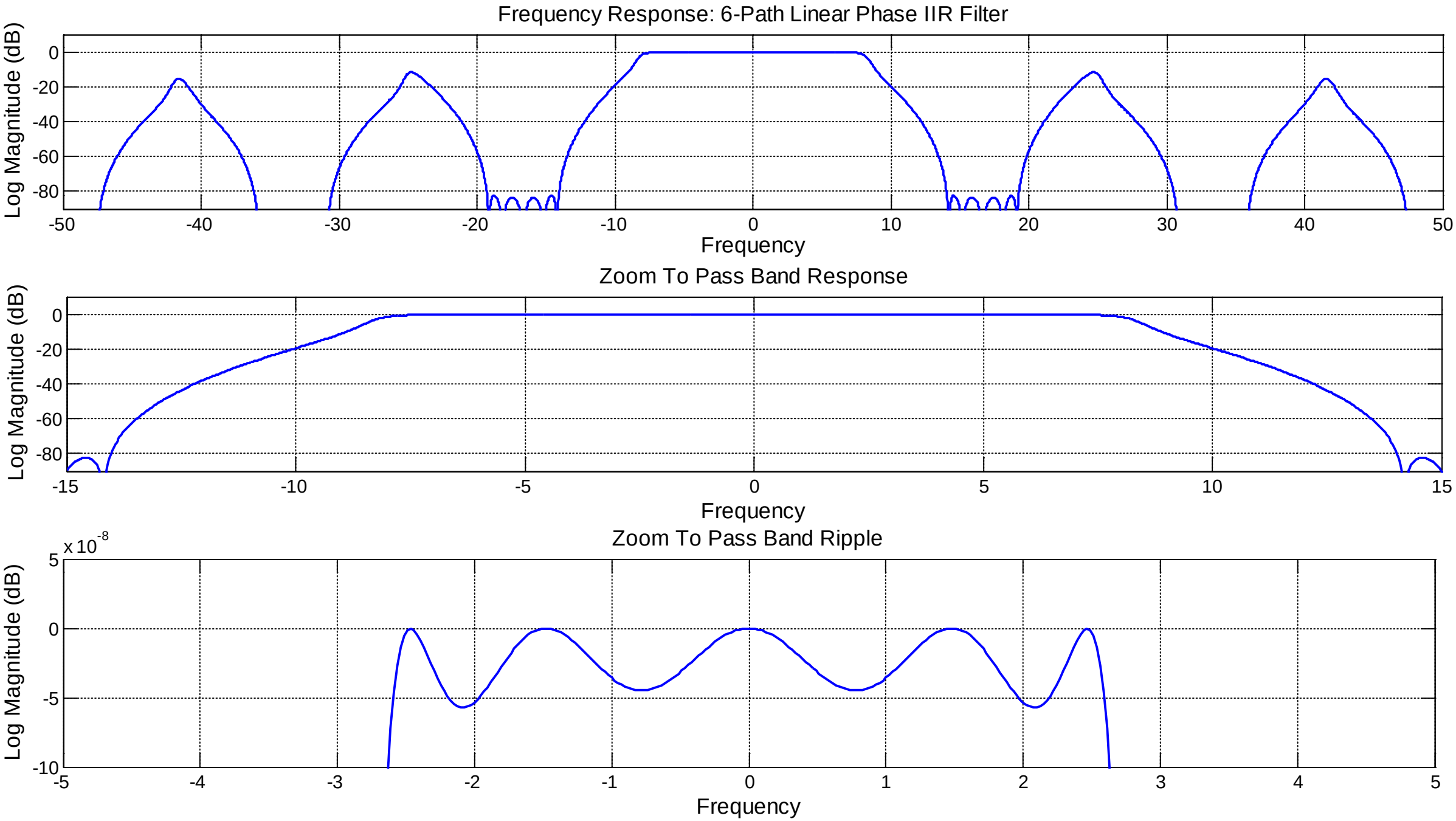
6 Path Cascade Filter

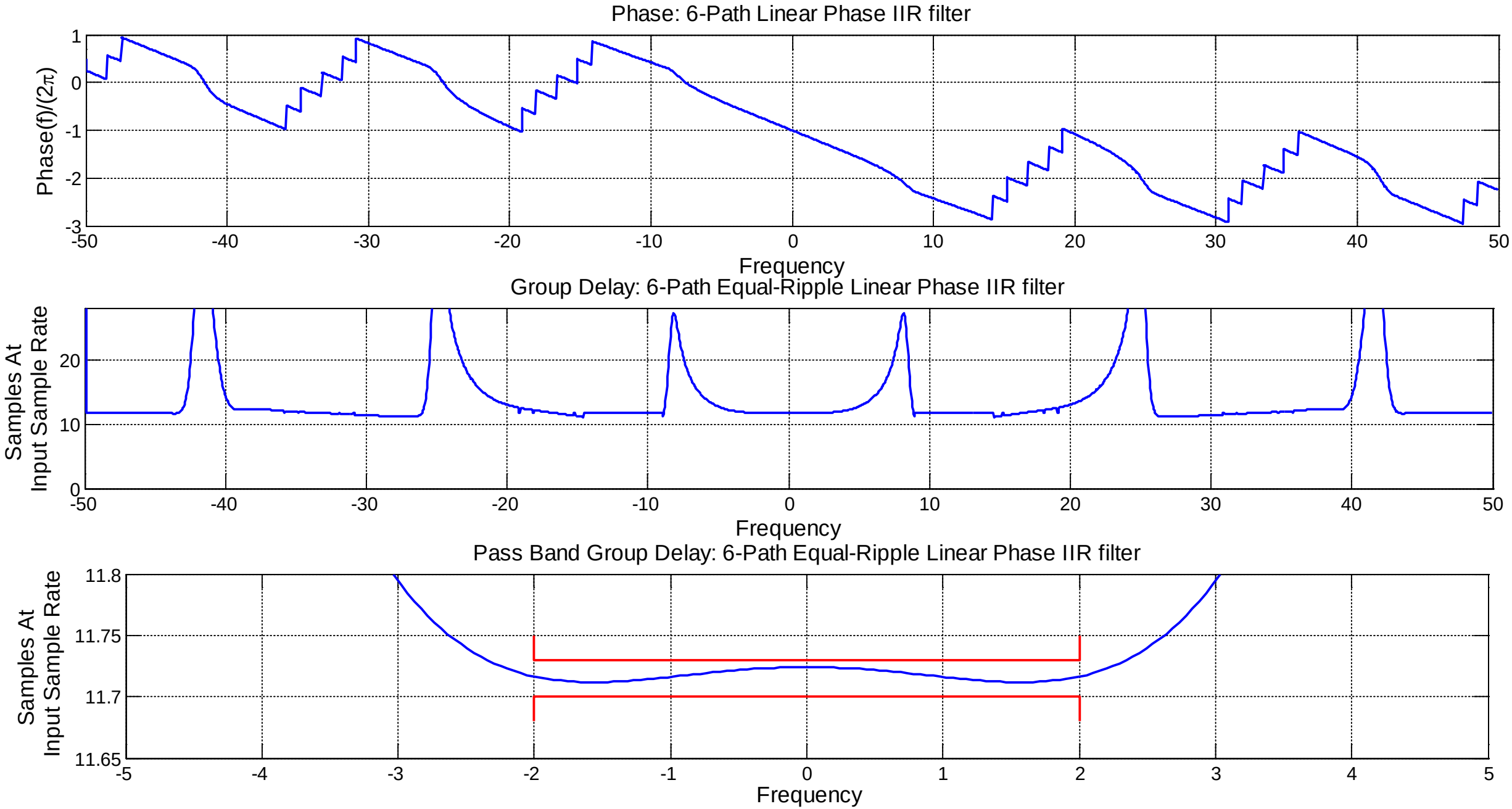


6-Path Filter with 2- First Order IIR Filters

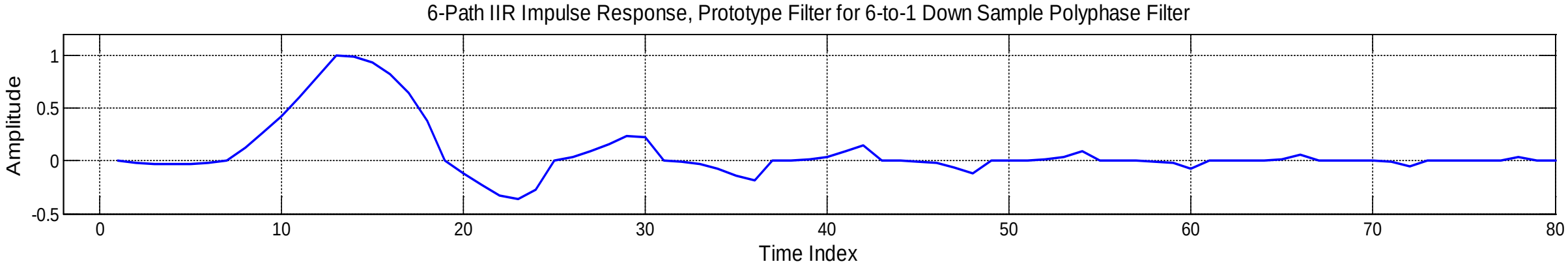


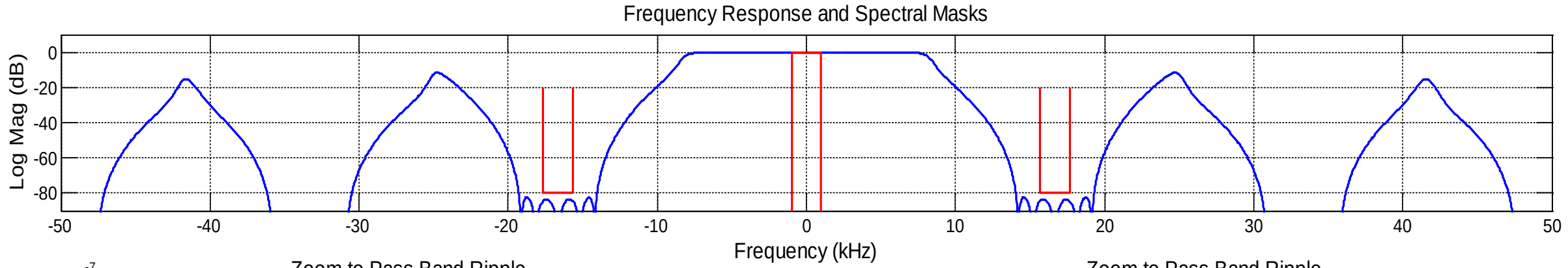

Pole-Zero Diagram
Don’t Care Band
Stop Band
Stop Band
Don’t Care Band
Stop Band
Pass Band
Don’t Care Band
Stop Band
Stop Band
Don’t care Band
1.5
1
0.5
0
-0.5
-1
-1.5
-1.5
-1
-0.5
0
0.5
1
1.5

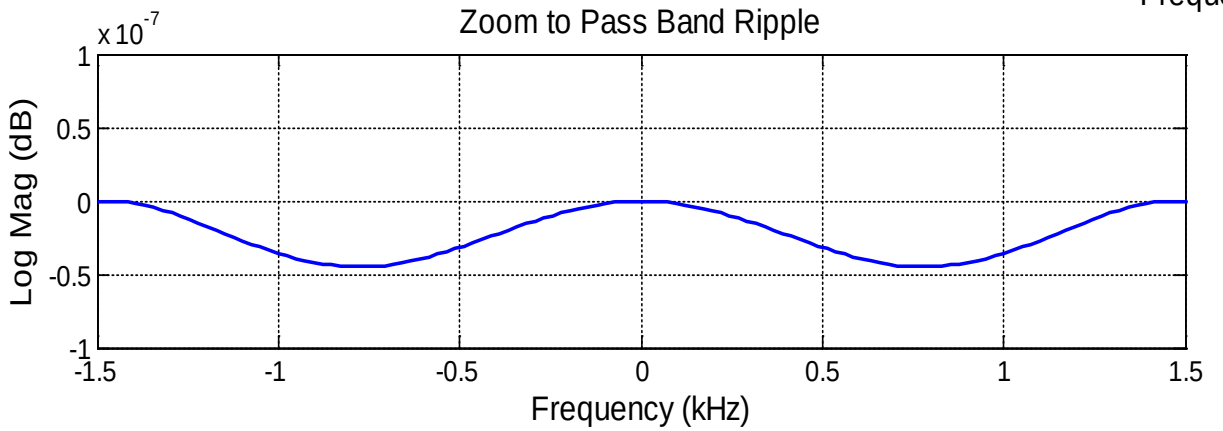

Frequency Response: 6-Path Linear Phase IIR Filter
Log Magnitude (dB)
0
-20
-40
-60
-80
-50
-40
-30
-20
-10
0
10
20
30
40
50
Frequency
Zoom To Pass Band Response
Log Magnitude (dB)
0
-20
-40
-60
-80
-15
-10
-5
0
5
10
15
Frequency
Zoom To Pass Band Ripple
x 10^-8
Log Magnitude (dB)
5
0
-5
-10
-5
-4
-3
-2
-1
0
1
2
3
4
5
Frequency

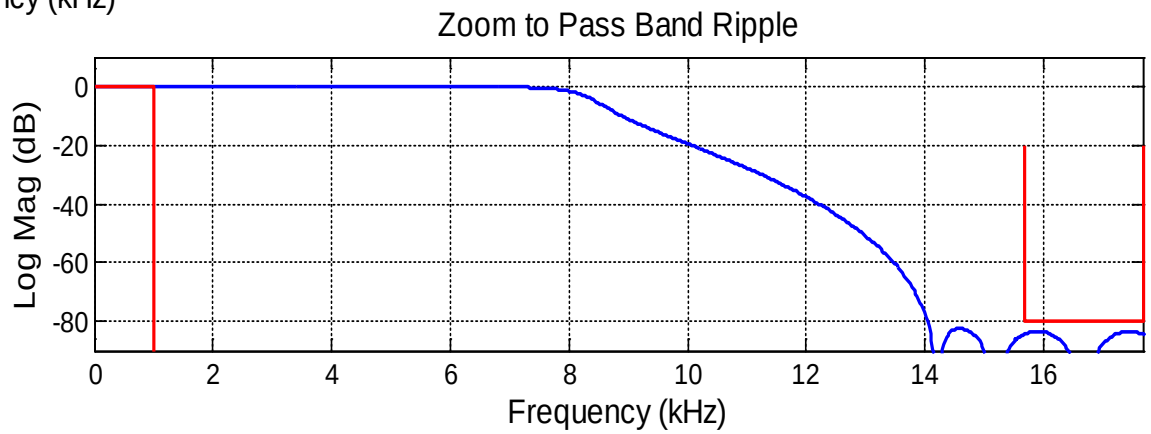

Phase: 6-Path Linear Phase IIR filter
Phase(f)/(2π)
1
0
-1
-2
-3
-50
-40
-30
-20
-10
0
10
20
30
40
50
Frequency
Group Delay: 6-Path Equal-Ripple Linear Phase IIR filter
Samples At
Input Sample Rate
20
10
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Frequency
Pass Band Group Delay: 6-Path Equal-Ripple Linear Phase IIR filter
Samples At
Input Sample Rate
11.8
11.75
11.7
11.65
-5
-4
-3
-2
-1
0
1
2
3
4
5
Frequency

6-Path Linear Phase Recursive Filter

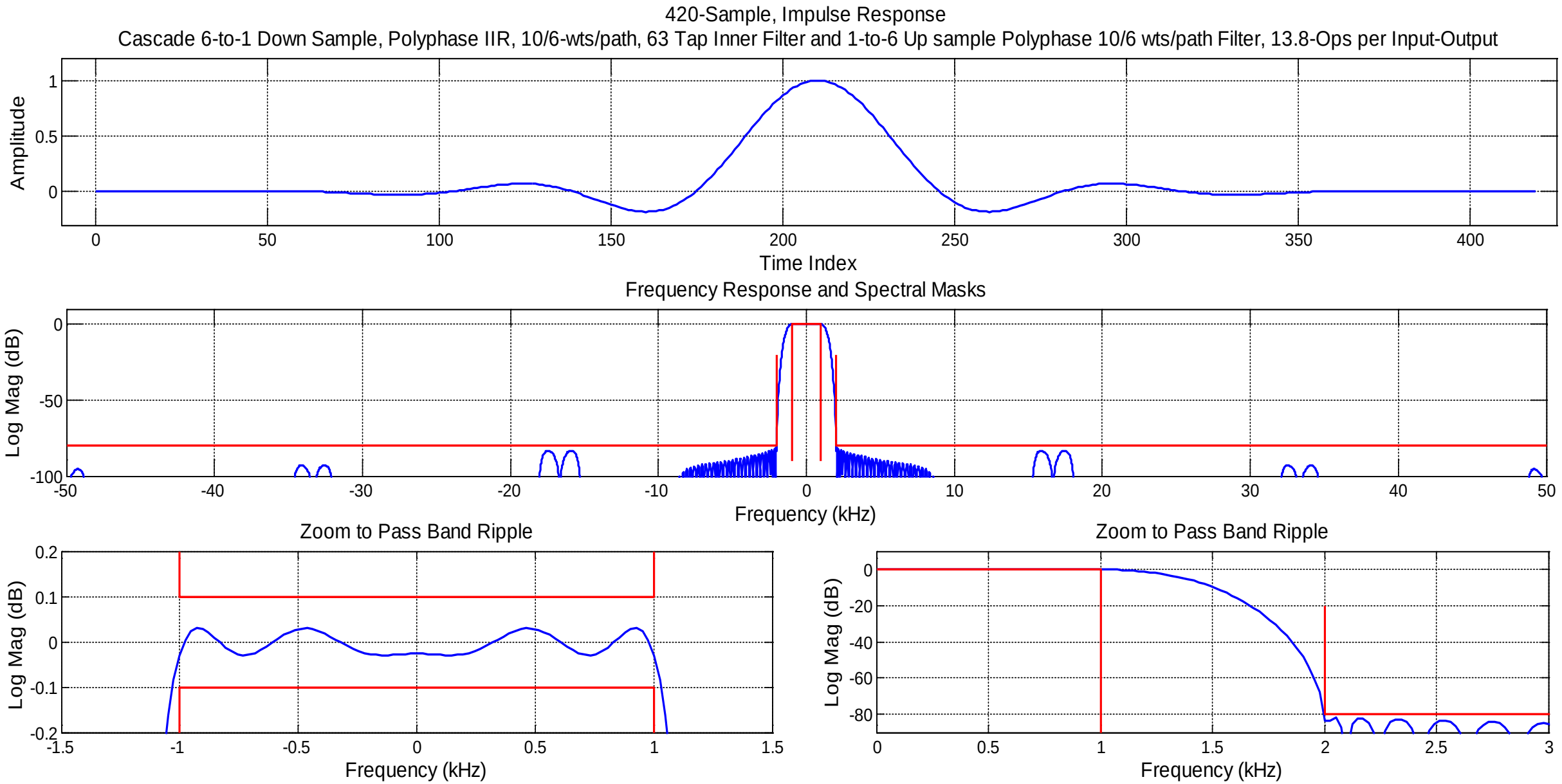






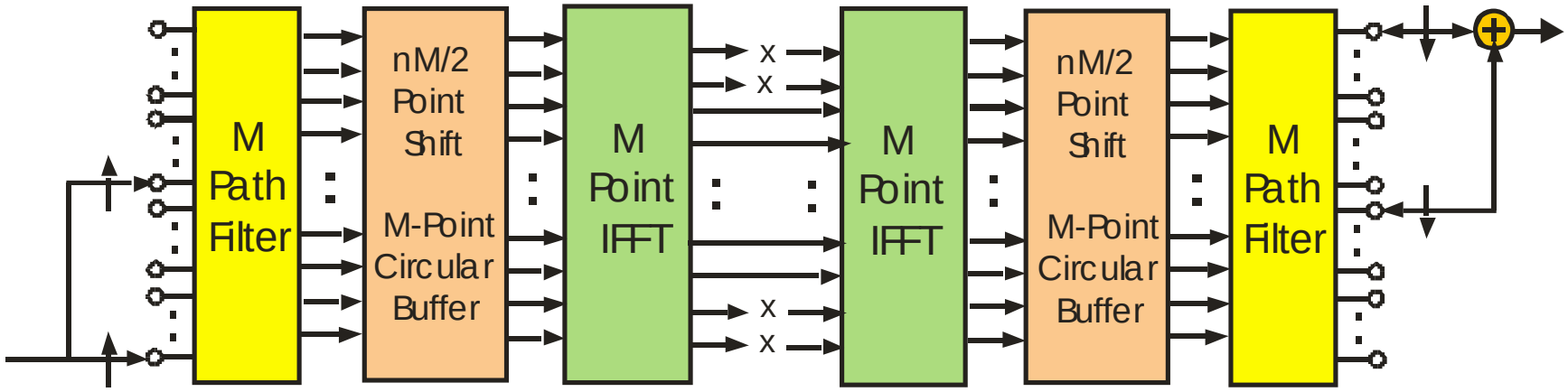


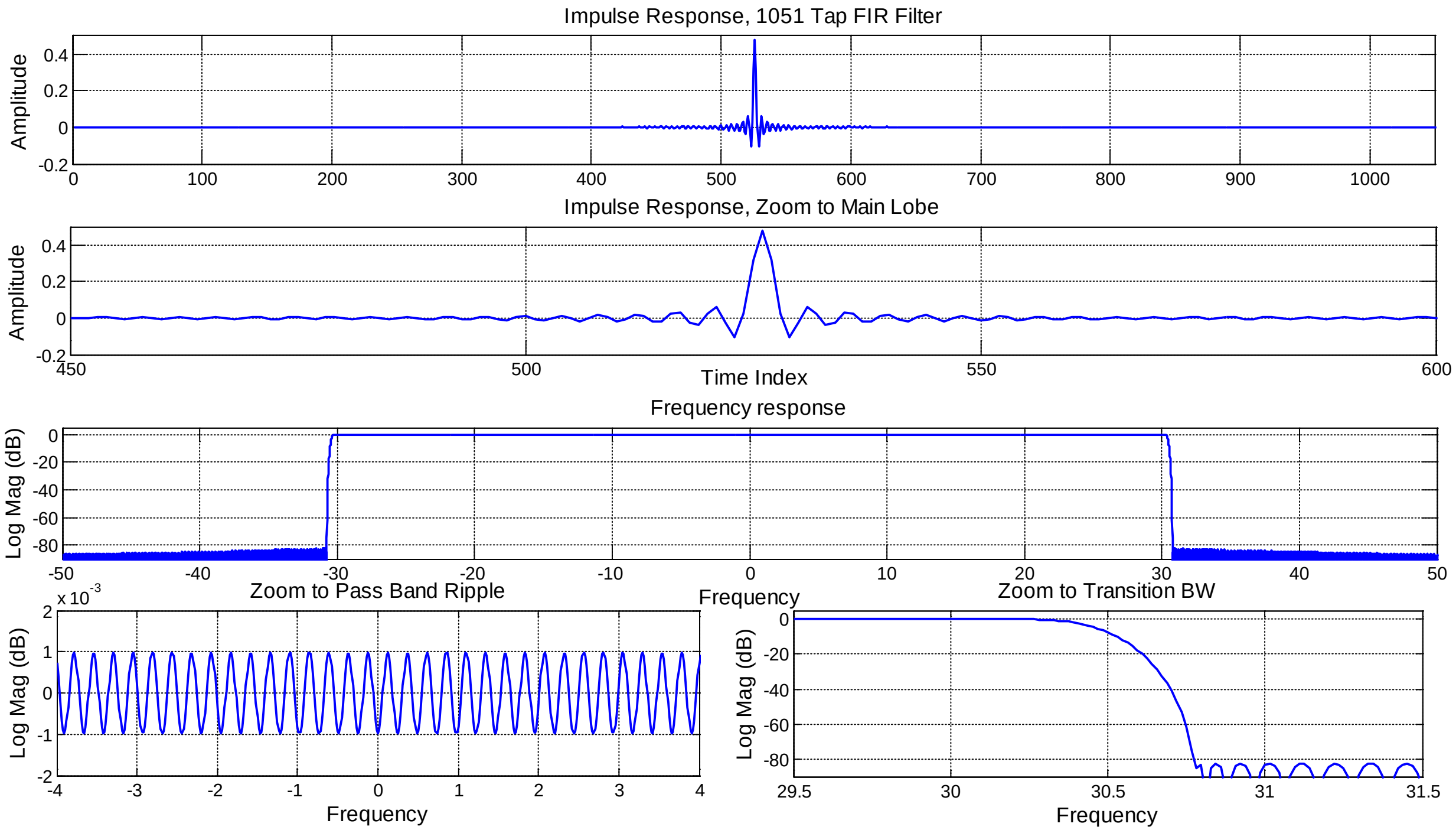
Cascade 6-Path Chain with Linear Phase Recursive Filter

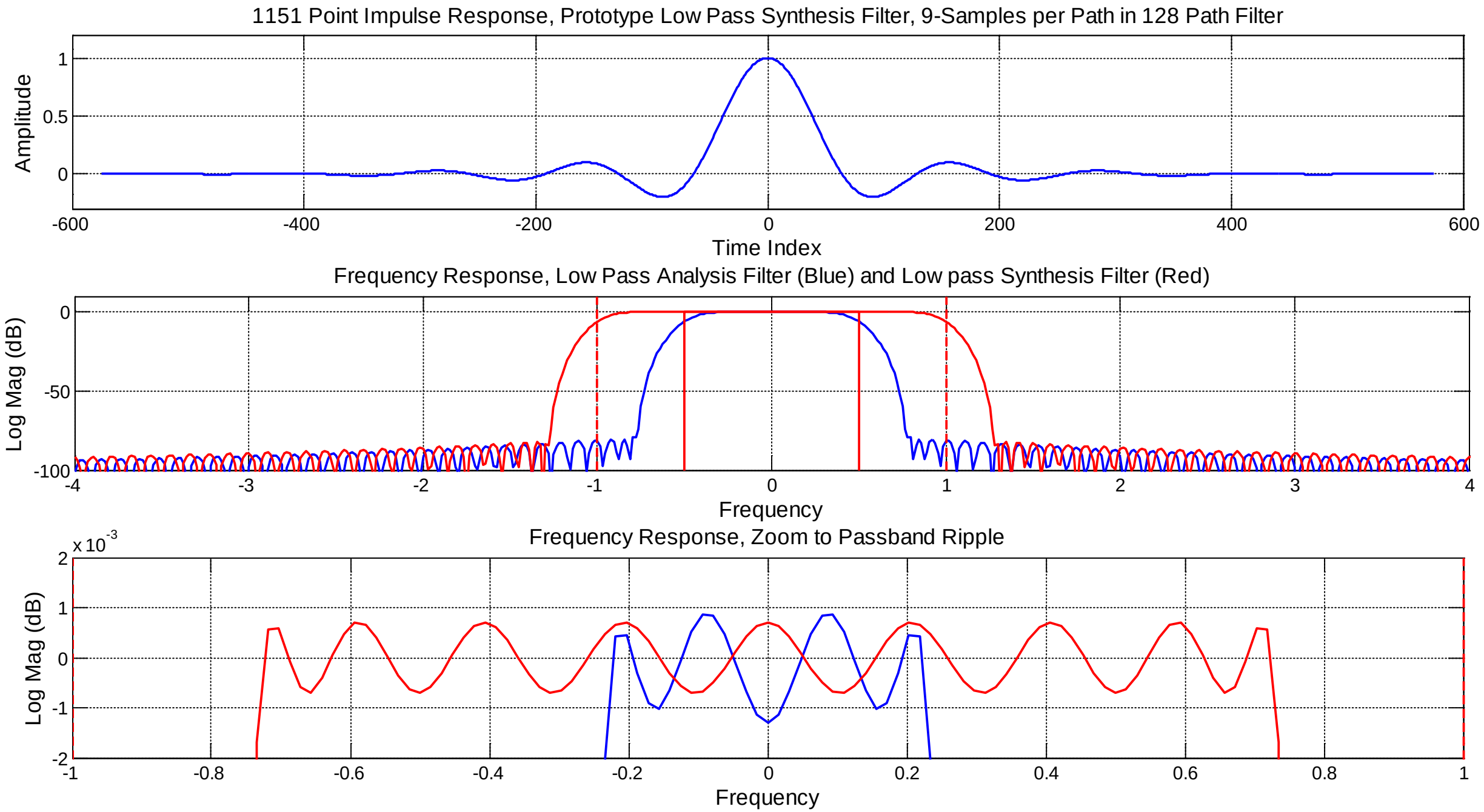


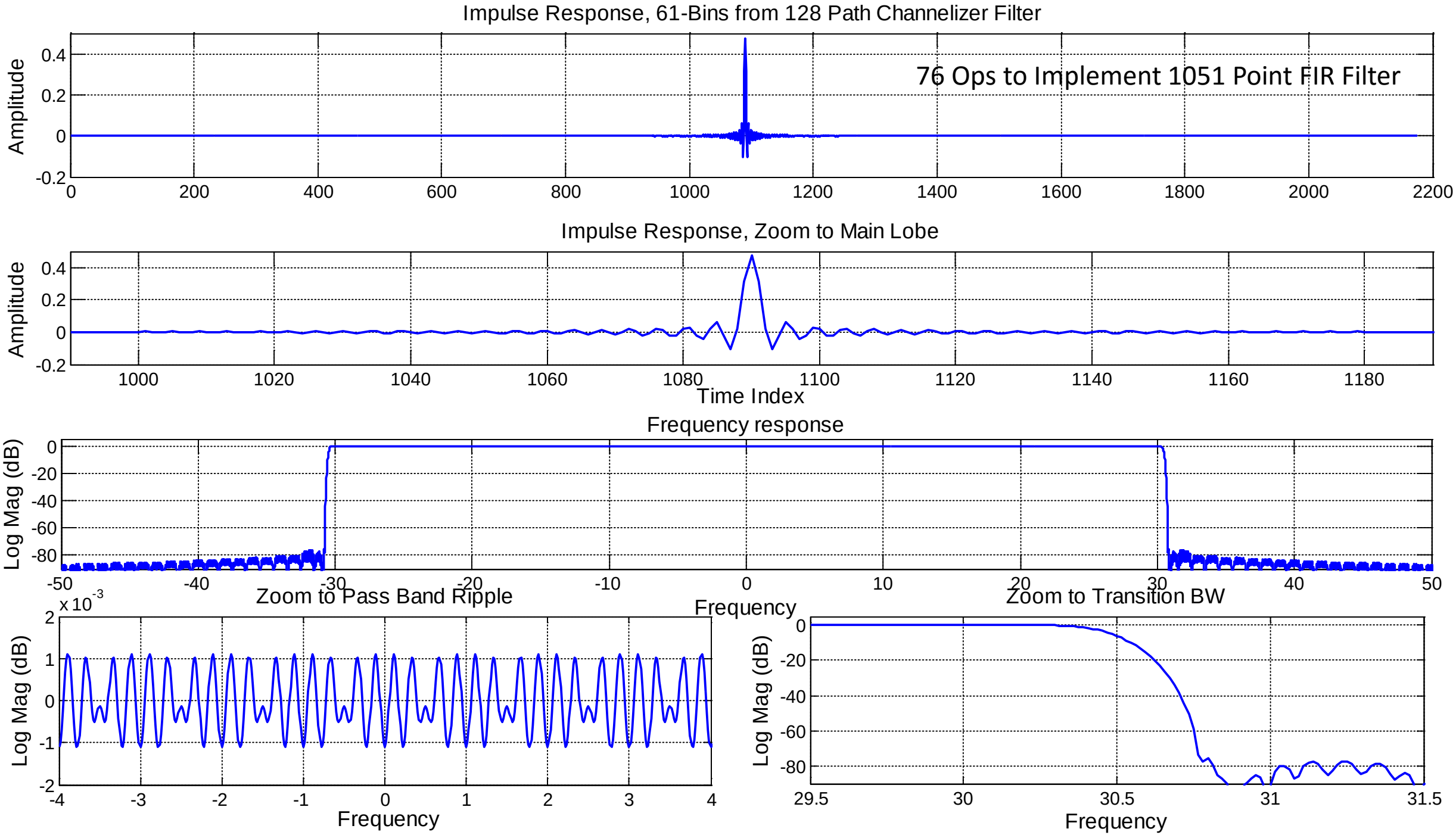
- Significant Computational Savings for Narrow Bandwidth Signals with Large Ratio of Sample Rate to BW (Allow Down-Sampling)
- How do we Access these Savings for Wide Bandwidth Signals?
- Partition the Wide Bandwidth Signal into Multiple Narrow Bandwidth Segments with each having Large Ratio of Sample Rate to BW!
- An Input Analysis Channelizer Does the Partition and Down Sampling
- An Output Synthesis Channelizer Does Reconstruction and Up Sampling

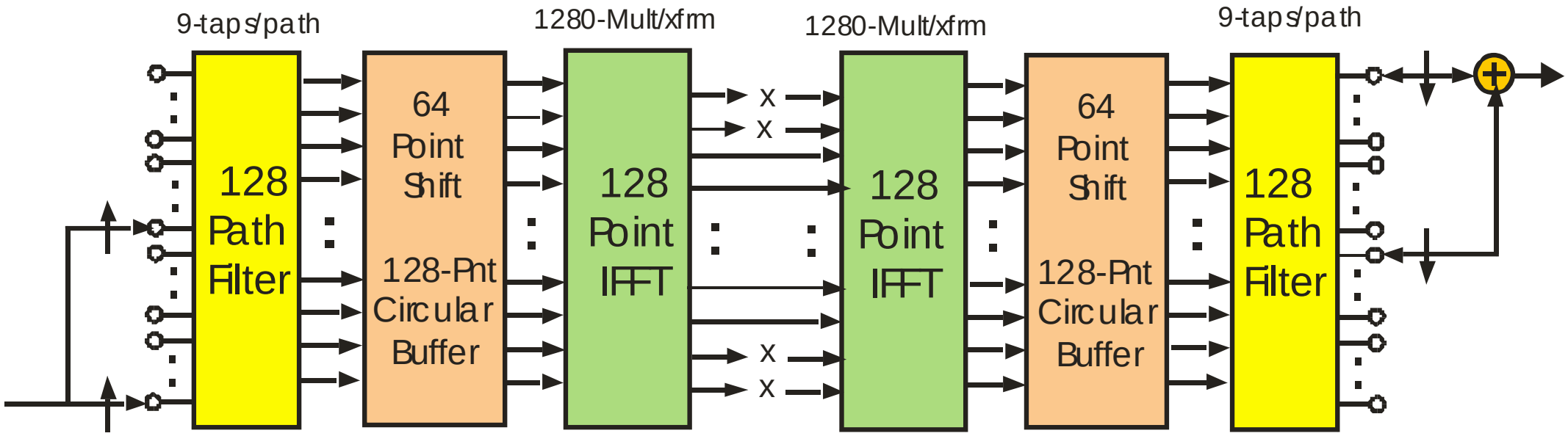
Filtering in the Channelizer Domain



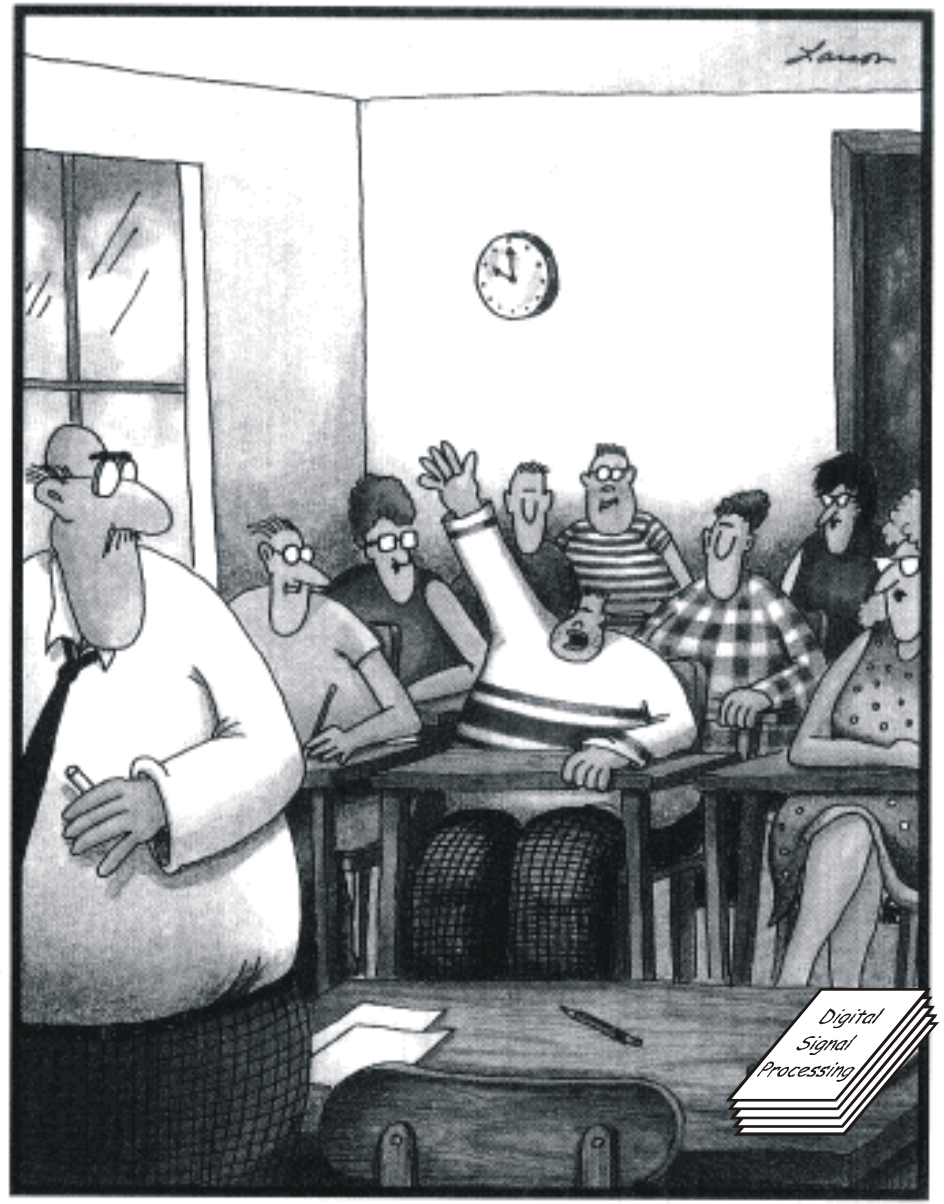

Impulse Response, 1051 Tap FIR Filter
Amplitude
0.4
0.2
0
-0.2
0
100
200
300
400
500
600
700
800
900
1000
Impulse Response, Zoom to Main Lobe
Amplitude
0.4
0.2
0
-0.2
450
500
550
600
Time Index
Frequency response
Log Mag (dB)
0
-20
-40
-60
-80
-50
-40
-30
-20
-10
0
10
20
30
40
50
Frequency
Zoom to Pass Band Ripple
x 10^-3
Log Mag (dB)
2
1
0
-1
-2
-4
-3
-2
-1
0
1
2
3
4
Frequency
Zoom to Transition BW
Log Mag (dB)
0
-20
-40
-60
-80
29.5
30
30.5
31
31.5
Frequency


1151 Point Impulse Response, Prototype Low Pass Synthesis Filter, 9-Samples per Path in 128 Path Filter
Amplitude
1
0.5
0
-600
-400
-200
0
200
400
600
Time Index
Frequency Response, Low Pass Analysis Filter (Blue) and Low pass Synthesis Filter (Red)
Log Mag (dB)
0
-50
-100
-4
-3
-2
-1
0
1
2
3
4
Frequency
Frequency Response, Zoom to Passband Ripple
x 10^-3
Log Mag (dB)
2
1
0
-1
-2
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Frequency


Impulse Response, 61-Bins from 128 Path Channelizer Filter
Amplitude
76 Ops to Implement 1051 Point FIR Filter
Impulse Response, Zoom to Main Lobe
Amplitude
Time Index
Frequency response
Log Mag (dB)
Frequency
Zoom to Pass Band Ripple
x 10^-3
Log Mag (dB)
Frequency
Zoom to Transition BW
Log Mag (dB)
Frequency



Input Polyphase Filter 18 Ops/Input,
Output Polyphase Filter, 18 Ops/Output
128 point IFFTs, Approximately 1280 Multiplies/Transform,
1280 Ops Amortized over 64 Inputs is 20 Ops/Input
Total workload, 18+20+20+18... 76 Ops/Input-Output
Direct Filter 1051 Samples... Ratio 1051/76, 13.8 to 1



Professor harris, may I be excused?
My brain is full.

We are open for questions.