

## CHAPTER 12

# Multirate Signal Processing

### Basic Problems

19. (a) See plot below.

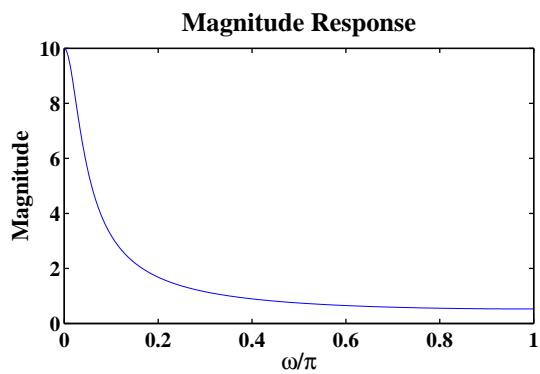
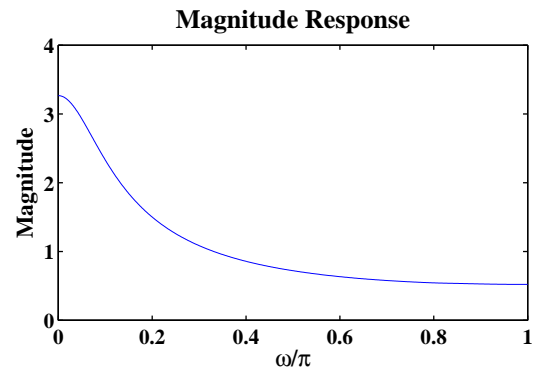


FIGURE 12.1: Magnitude spectra of  $x[n]$ .

- (b) See plot below.  
(c) tba.

FIGURE 12.2: Magnitude spectra of  $x_D[n]$ .

20. Solution:

$$y[n] = \sum_{m=-\infty}^{\infty} x[3m]g_r[n - 5m]$$

21. (a) See plot below.

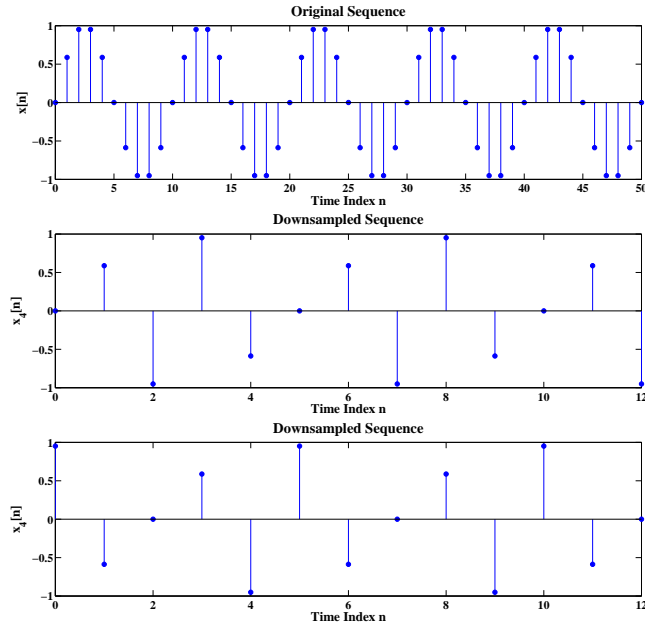


FIGURE 12.3: Stem plots of  $x[n] = \sin(0.2\pi n)$  and downsampled sequences for  $D = 4$ ,  $k = 0$ , and  $k = 2$ .

- (b)  $x[n] = \cos(0.3\pi n)$ ,  $0 \leq n \leq 60$ ,  $D = 3$ ,  $k = 0$ , and  $k = 1$ .
- (c) See plot below.
- (d) See plot below.
- (e) See plot below.

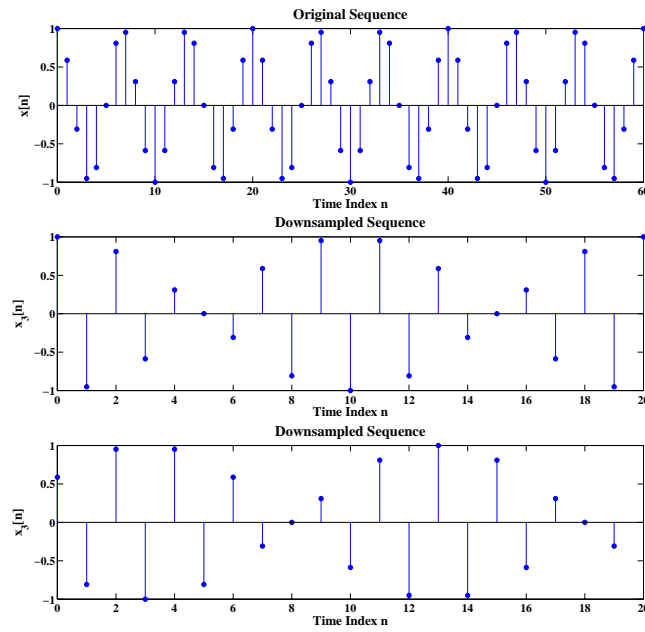


FIGURE 12.4: Stem plots of  $x[n] = \cos(0.3\pi n)$  and downsampled sequences for  $D = 3$ ,  $k = 0$ , and  $k = 1$ .

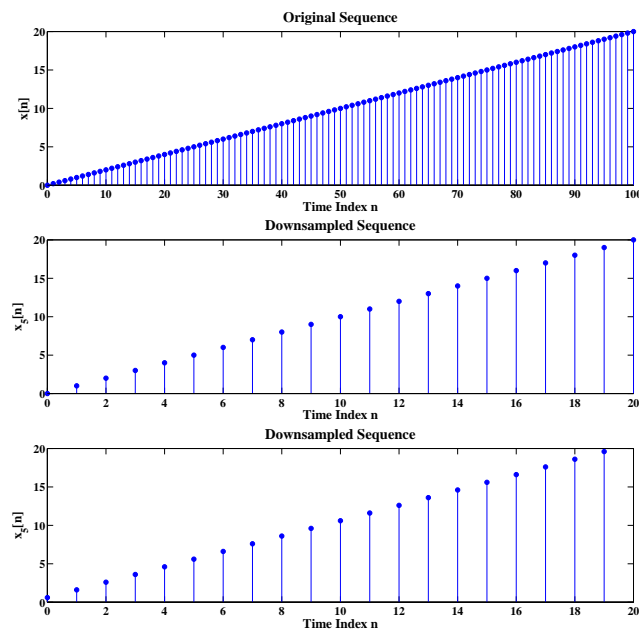


FIGURE 12.5: Stem plots of  $x[n] = 0.2n$  and downsampled sequences for  $D = 5$ ,  $k = 0$ , and  $k = 3$ .

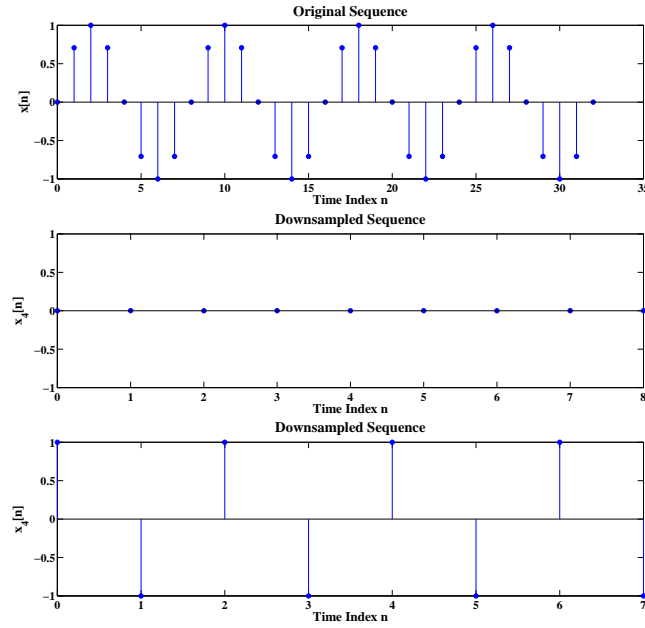


FIGURE 12.6: Stem plots of  $x[n] = \sin(0.25\pi n)$  and downsampled sequences for  $D = 4$ ,  $k = 0$ , and  $k = 2$ .

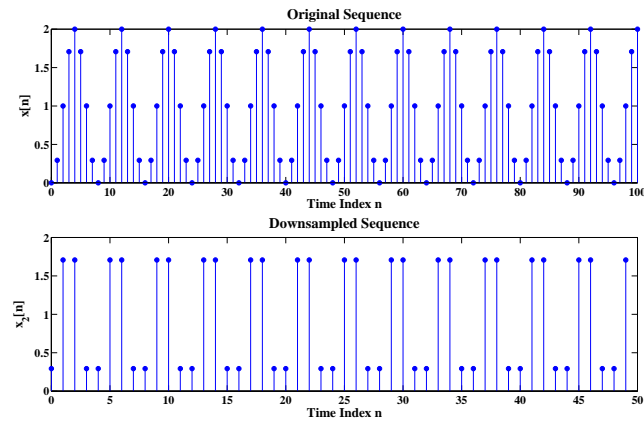


FIGURE 12.7: Stem plots of  $x[n] = 1 - \cos(0.6\pi n)$  and downsampled sequences for  $D = 2$ ,  $k = 1$ .

22. (a) See plot below.

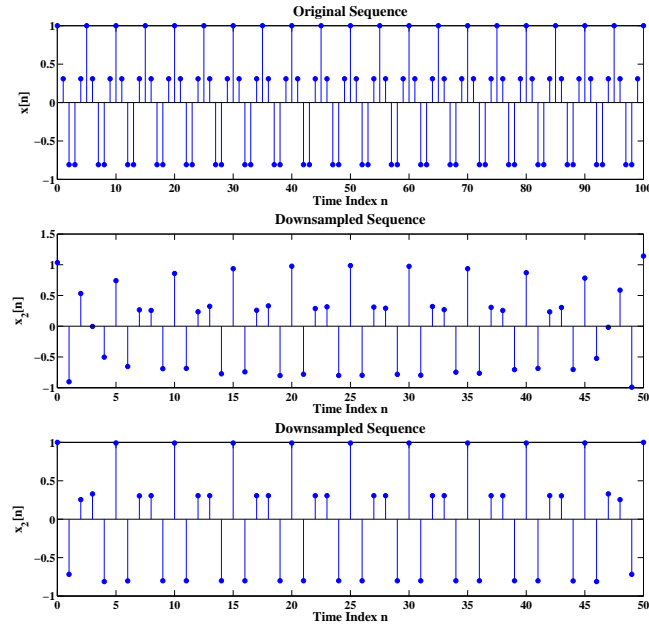


FIGURE 12.8: Stem plots of  $x[n] = \cos(0.4\pi n)$  and downsampled sequences for  $D = 2$  using both the default IIR and FIR decimation filters.

- (b) See plot below.
- (c) See plot below.
- (d) See plot below.
- (e) See plot below.

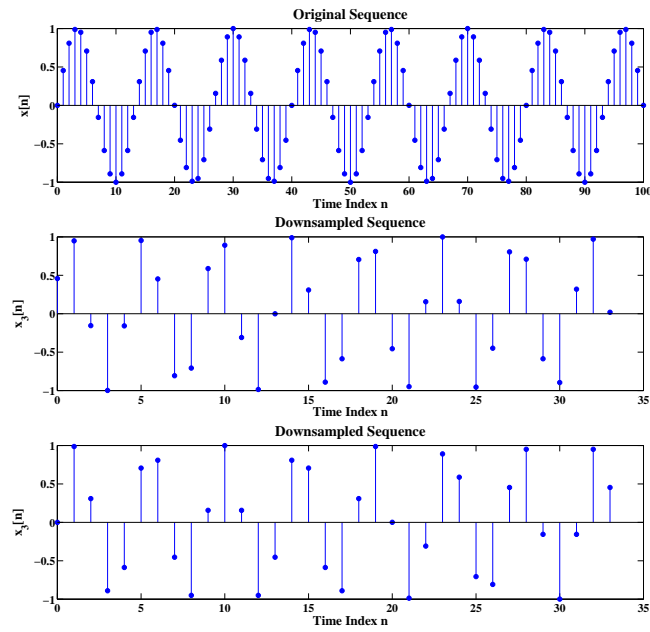


FIGURE 12.9: Stem plots of  $x[n] = \sin(0.15\pi n)$  and downsampled sequences for  $D = 3$  using both the default IIR and FIR decimation filters.



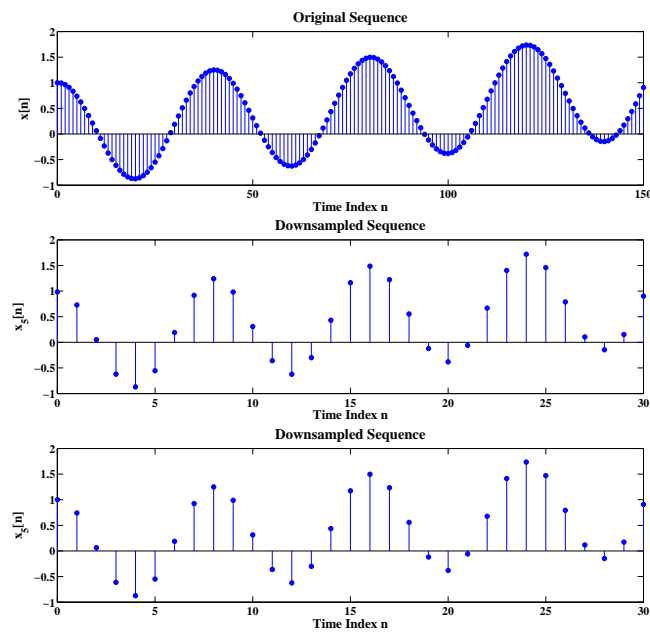


FIGURE 12.10: Stem plots of  $x[n] = \cos(0.05\pi n) + 2 \sin 0.001\pi n$  and downsampled sequences for  $D = 5$  using both the default IIR and FIR decimation filters.

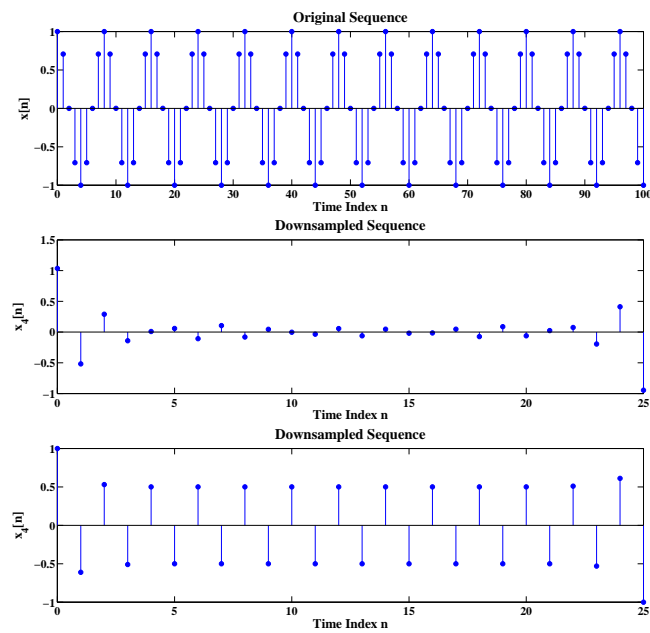


FIGURE 12.11: Stem plots of  $x[n] = \cos(0.25\pi n)$  and downsampled sequences for  $D = 4$  using both the default IIR and FIR decimation filters.

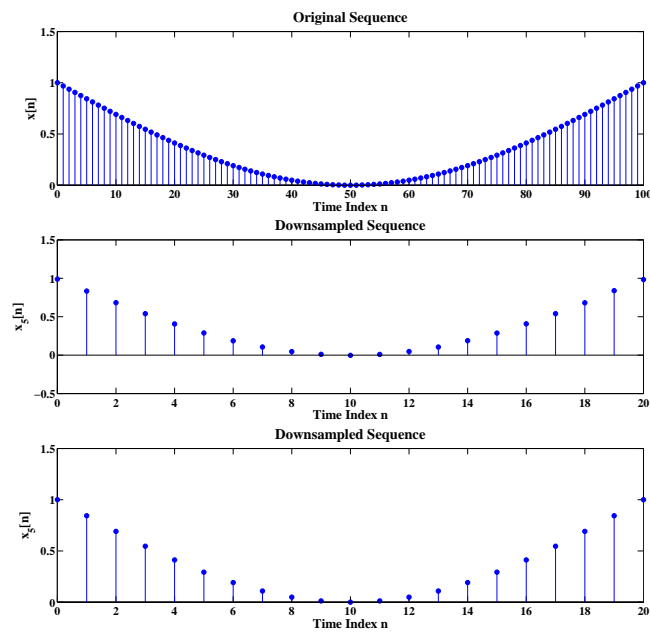


FIGURE 12.12: Stem plots of  $x[n] = 1 - \sin(0.01\pi n)$  and downsampled sequences for  $D = 5$  using both the default IIR and FIR decimation filters.

23. (a) See script below.  
 (b) See plot below.

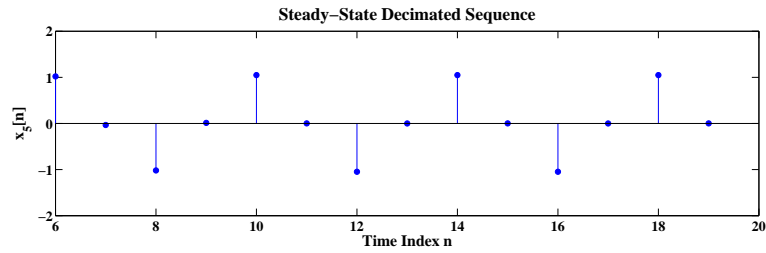


FIGURE 12.13: Steady-state values of  $x_d[n]$  by the decimator of Figure 12.5.

- (c) See plot below.

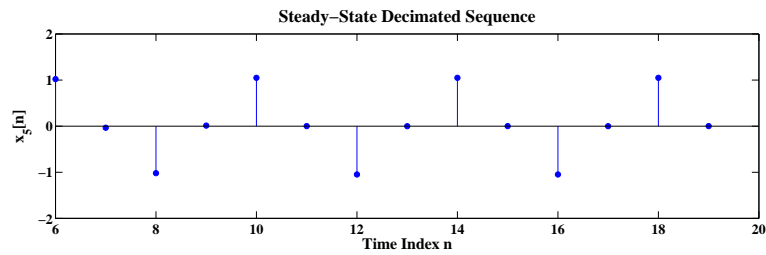


FIGURE 12.14: Steady-state values of  $x_d[n]$  by the decimator using the `firdec` function.

- (d) See plot below.  
 (e) See plot below.  
 (f) tba.

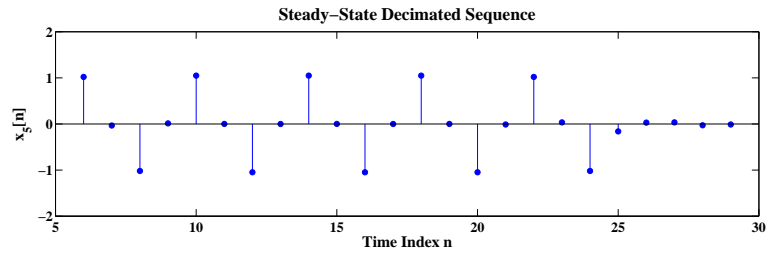


FIGURE 12.15: Steady-state values of  $x_d[n]$  by the decimator using the `upfirdn` function.

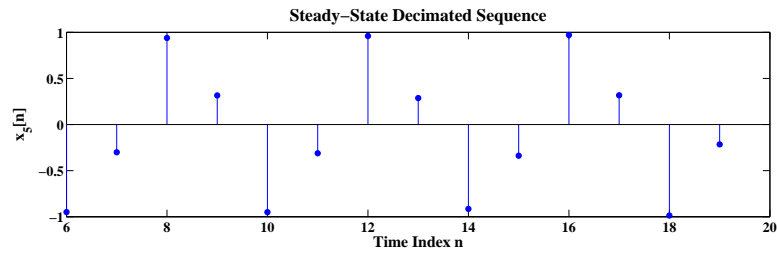


FIGURE 12.16: Steady-state values of  $x_d[n]$  by the decimator using the `decimate` function.

24. (a) See plot below.

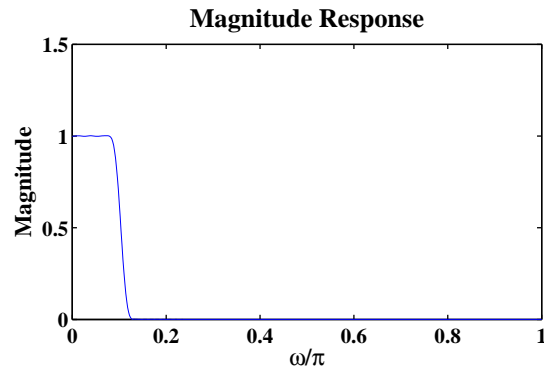


FIGURE 12.17: Magnitude spectra of  $x[n]$ .

(b) See plot below.

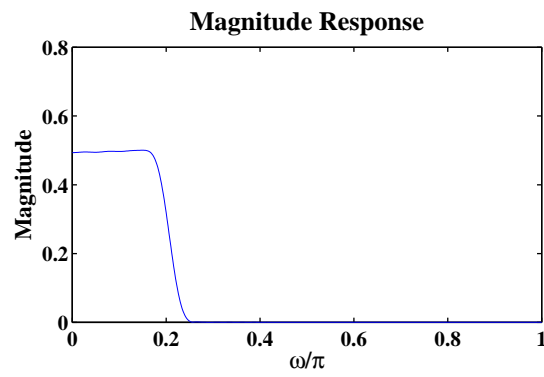
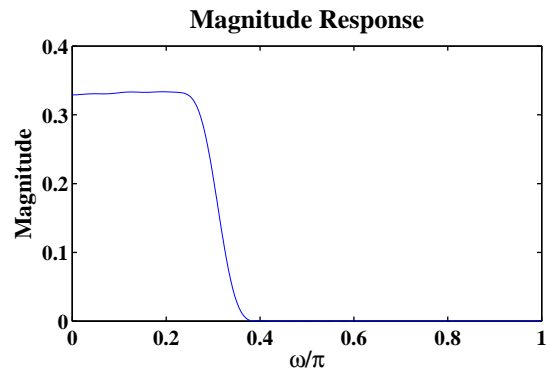
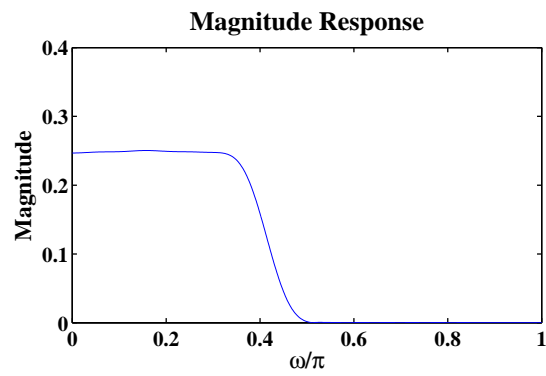


FIGURE 12.18: Magnitude spectra of decimated signal using  $D = 2$ .

(c) See plot below.

(d) See plot below.

(e) tba.

FIGURE 12.19: Magnitude spectra of decimated signal using  $D = 3$ .FIGURE 12.20: Magnitude spectra of decimated signal using  $D = 4$ .

25. (a) See plot below.

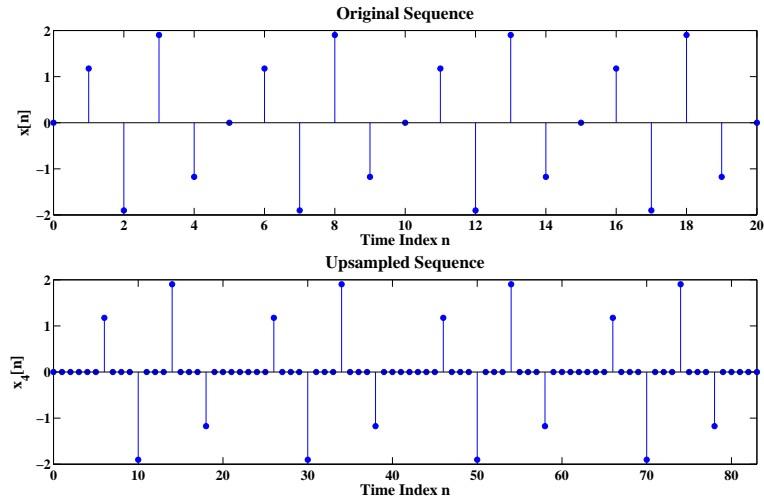


FIGURE 12.21: Stem plots of  $x[n] = 2 \sin(0.8\pi n)$  and upsampled sequences for  $I = 4$ .

- (b) See plot below.  
 (c) See plot below.  
 (d) See plot below.  
 (e) See plot below.



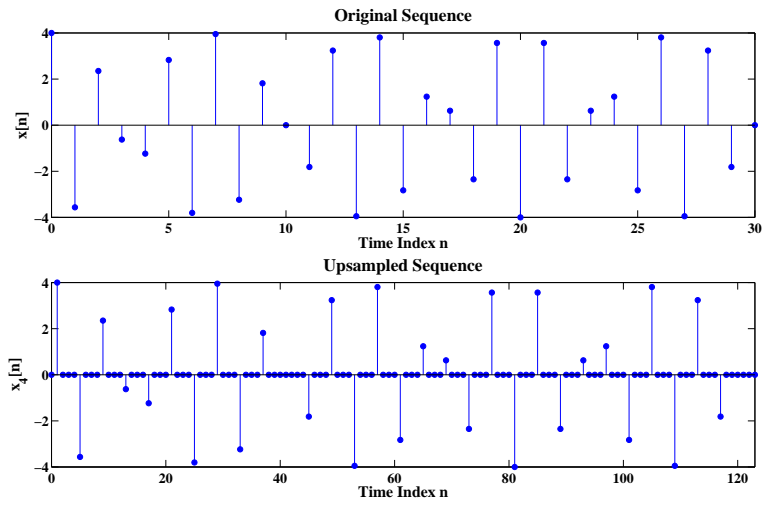


FIGURE 12.22: Stem plots of  $x[n] = 4 \cos(0.085\pi n)$  and upsampled sequences for  $I = 4$ .

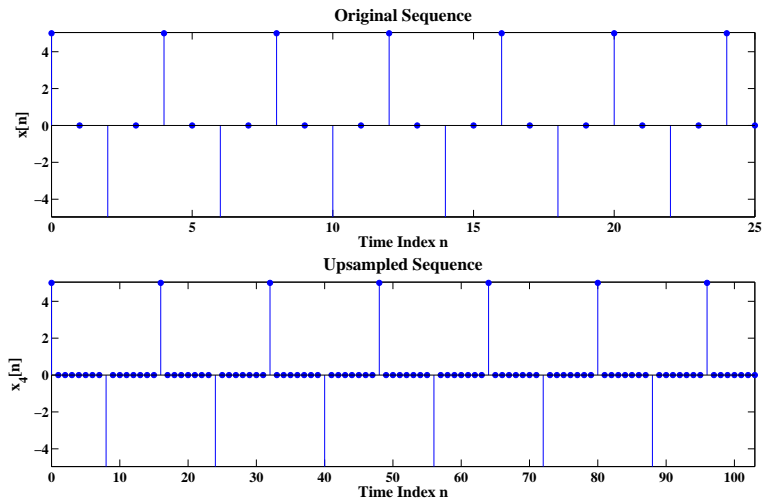


FIGURE 12.23: Stem plots of  $x[n] = 5 \cos(0.5\pi n)$  and upsampled sequences for  $I = 4$ .

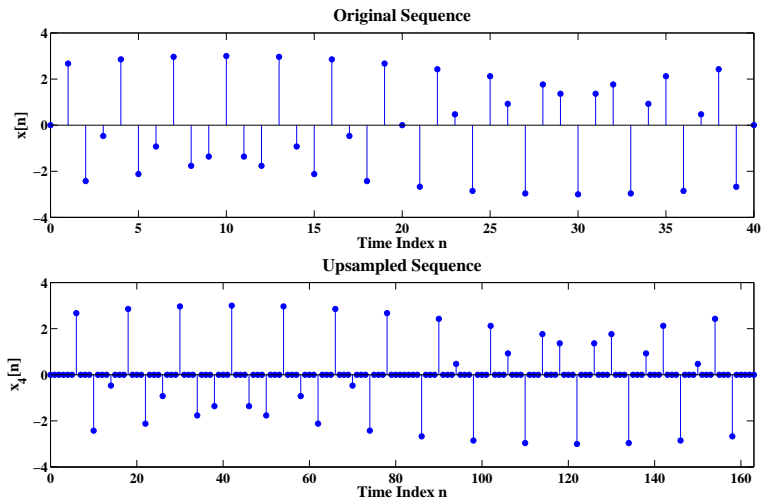


FIGURE 12.24: Stem plots of  $x[n] = 3 \sin(0.65\pi n)$  and upsampled sequences for  $I = 4$ .

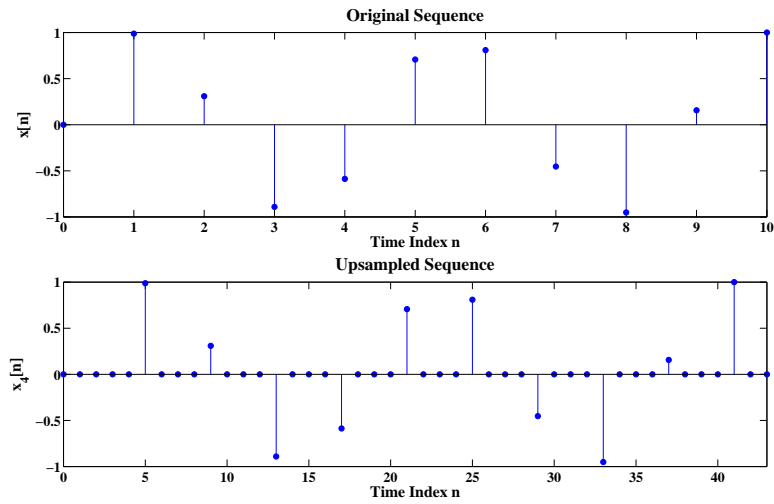


FIGURE 12.25: Stem plots of  $x[n] = \sin(0.45\pi n)$  and upsampled sequences for  $I = 4$ .

26. (a) See plot below.

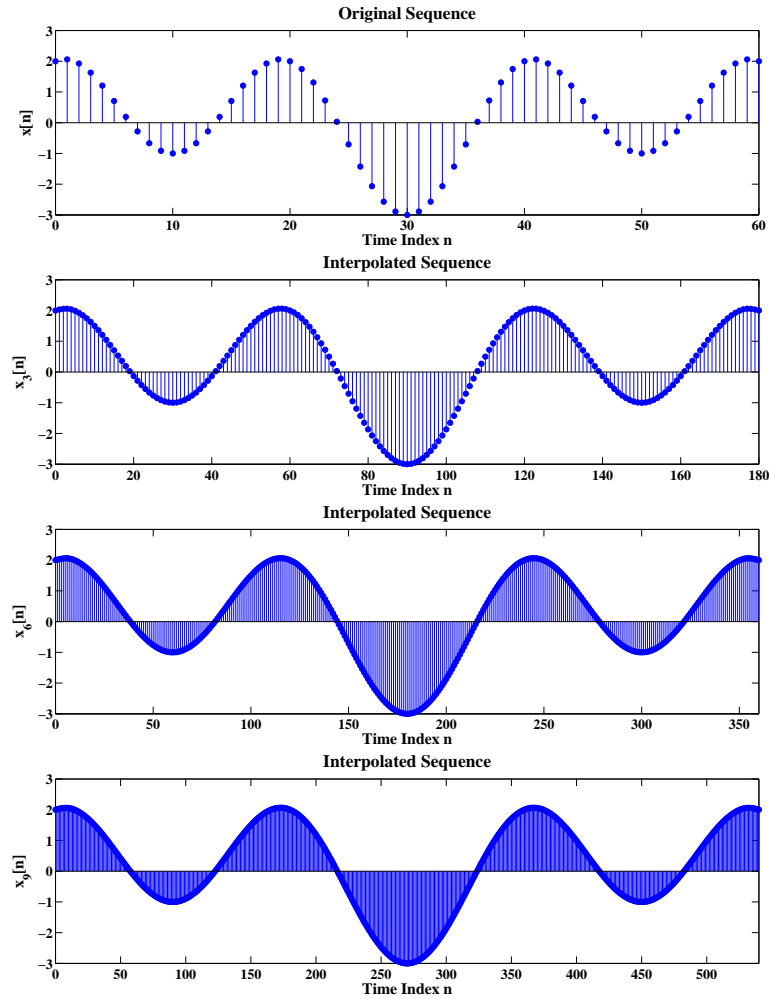


FIGURE 12.26: Stem plots of the original and interpolated signals for  $I = 3$ ,  $I = 6$ , and  $I = 9$ .

(b) See plot below.

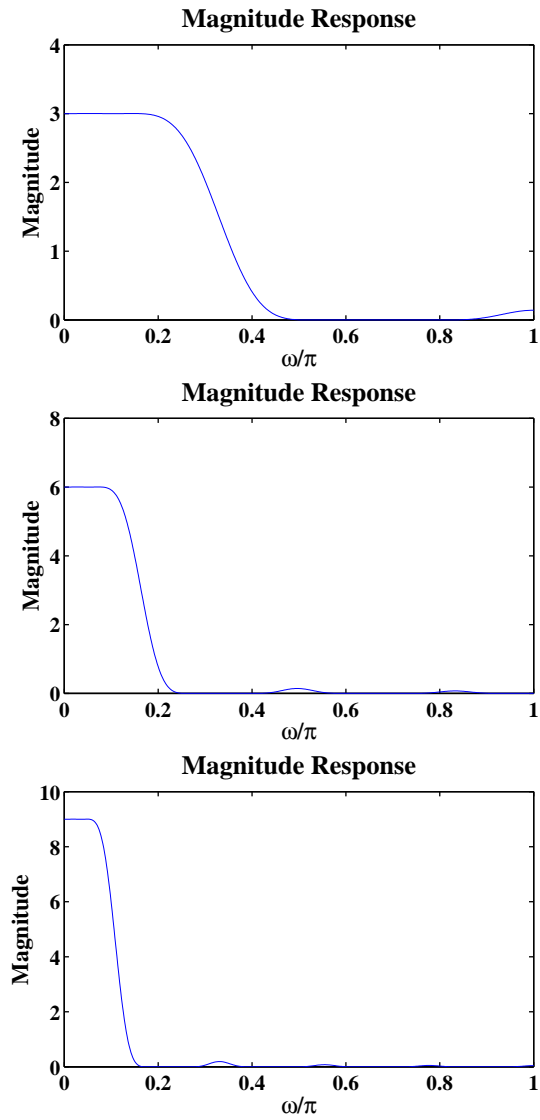


FIGURE 12.27: Magnitude responses of the lowpass filters used in interpolations for  $I = 3$ ,  $I = 6$ , and  $I = 9$ .

27. (a) See plot below.

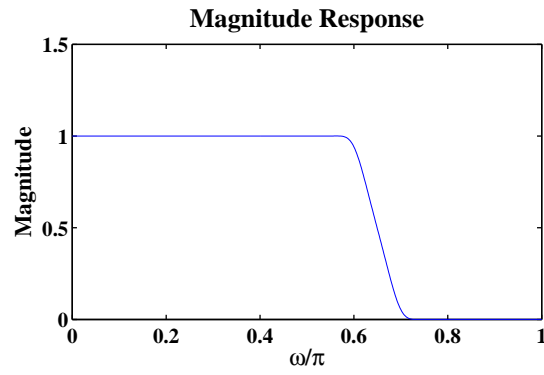


FIGURE 12.28: Magnitude responses of  $x[n]$ .

(b) See plot below.

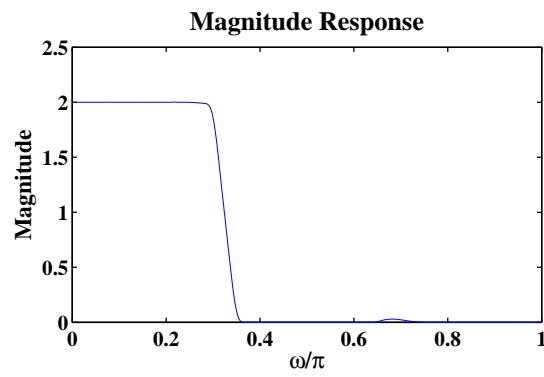
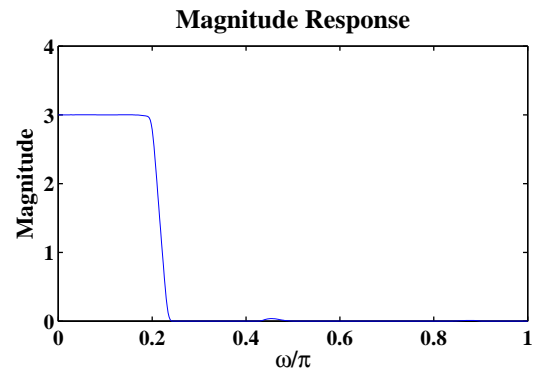
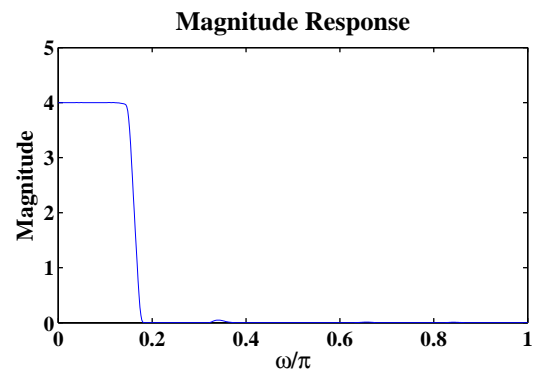


FIGURE 12.29: Magnitude responses of the upsampled signal using  $I = 2$ .

(c) See plot below.

(d) See plot below.

(e) tba.

FIGURE 12.30: Magnitude responses of the upsampled signal using  $I = 3$ .FIGURE 12.31: Magnitude responses of the upsampled signal using  $I = 4$ .

28. (a) See script below.  
 (b) See plot below.

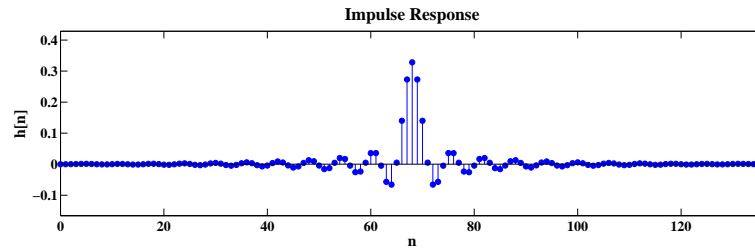


FIGURE 12.32: Stem plots of the impulse response of the designed filter.

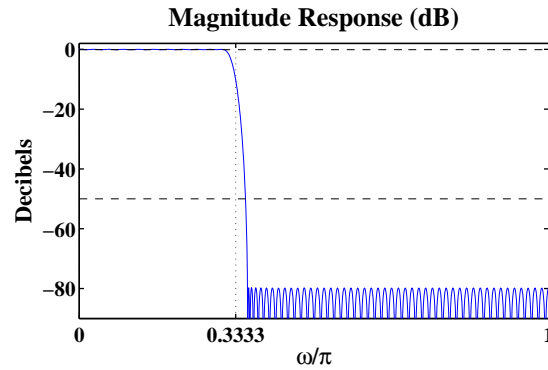


FIGURE 12.33: Log-magnitude response of the designed filter.

- (c) tba  
 (d) See plot below.

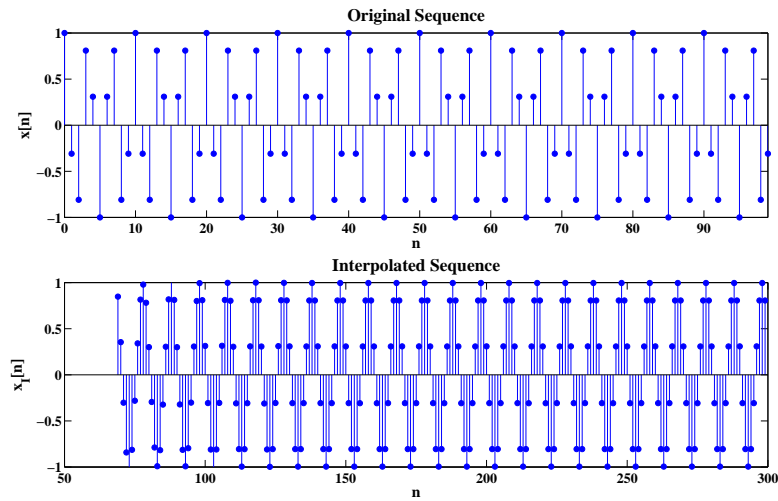


FIGURE 12.34: Stem plots of the original signal  $x[n] = \cos(0.6\pi n)$  and interpolated signal for  $I = 3$ .

29. (a) See plot below.

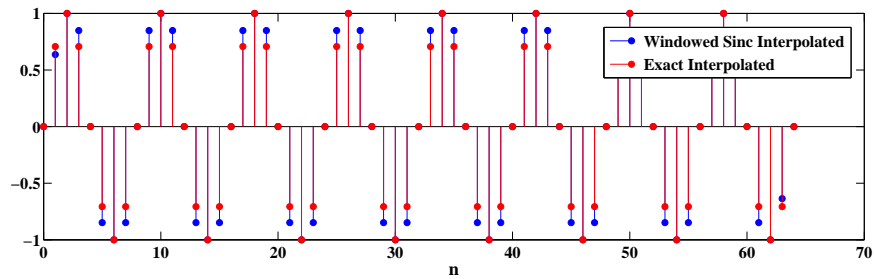


FIGURE 12.35: Stem plots of the interpolated signals by windowed sinc interpolation function compared with the exact interpolated sequence  $x[n]$ .

(b) tba



30. (a) See script below.  
 (b) See plot below.

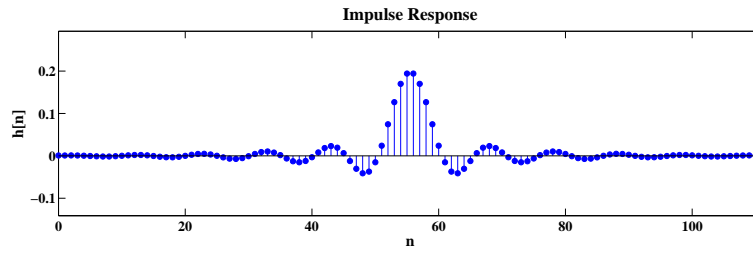


FIGURE 12.36: Impulse response of the designed filter.

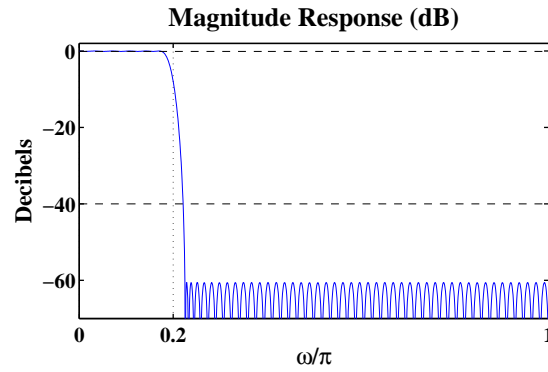


FIGURE 12.37: Log-magnitude response of the designed filter.

- (c) tba.  
 (d) See plot below.

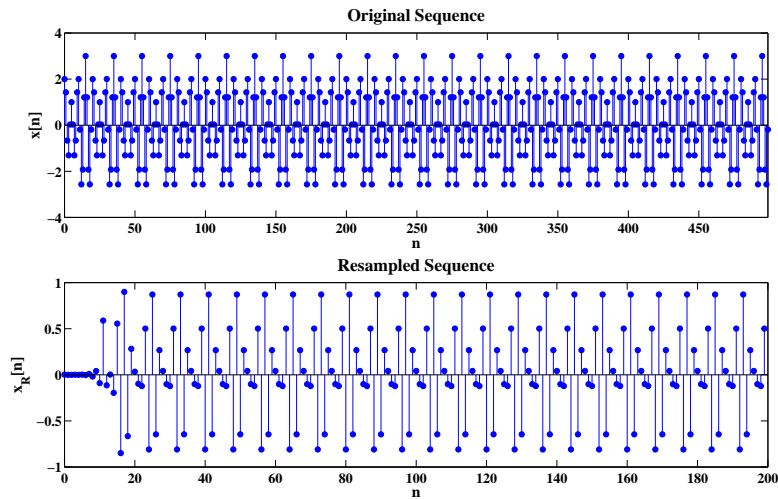


FIGURE 12.38: Stem plots of original sequence of  $x[n] = \sin(0.3\pi n) + 2\cos(0.4\pi n)$  and resampled sequence  $x_R[m]$  by  $2/5$ .

31. tba

32. (a) See plot below.

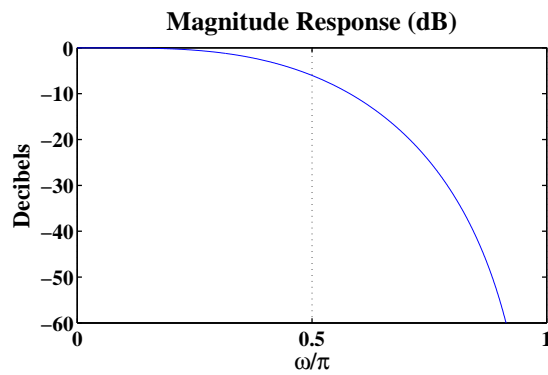


FIGURE 12.39: Log-magnitude response of the filter  $H(z)$ .

(b) tba.

33. See plot below.

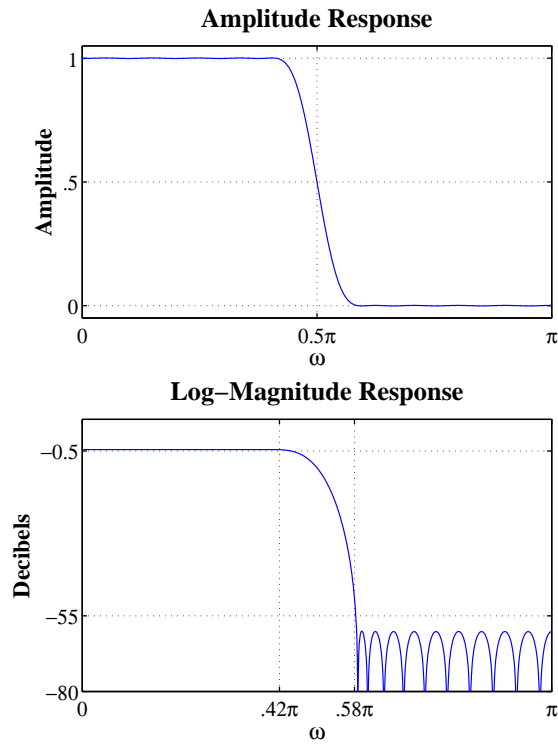


FIGURE 12.40: Amplitude response and log-magnitude response of the designed half-band filter.

34. (a) See plot below.

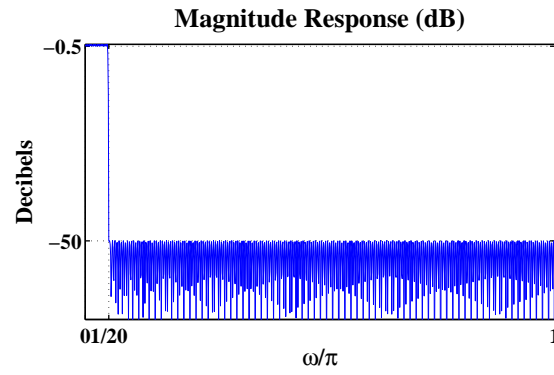


FIGURE 12.41: Log-magnitude response of the lowpass FIR filter of single-stage decimator.

- (b) See plot below.  
(c) See plot below.

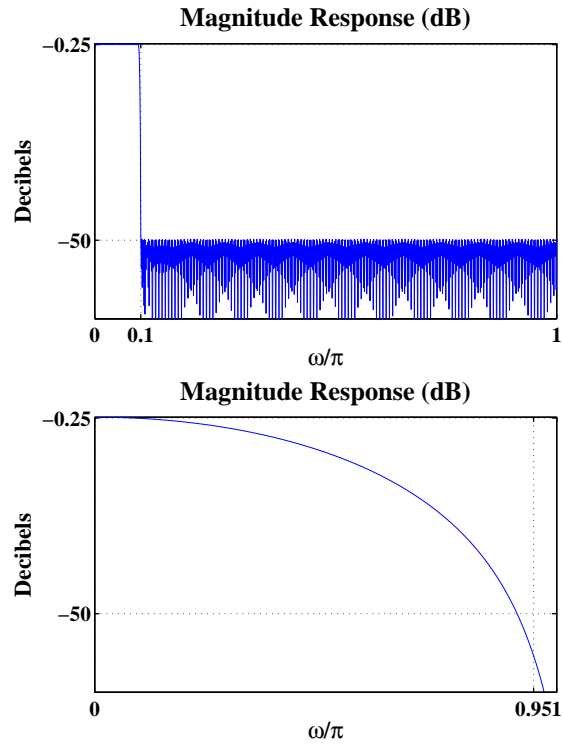


FIGURE 12.42: Log-magnitude responses of both filters of the two-stage decimator.

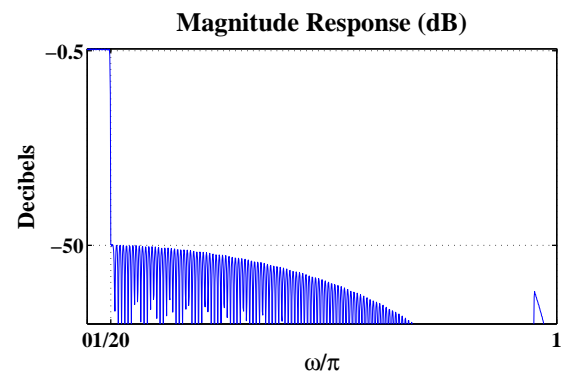


FIGURE 12.43: Log-magnitude response of the lowpass FIR filter of the equivalent single-stage filter from (b).