Bandpass Sampling (2B)

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Please send corrections (or suggestions) to youngwlim@hotmail.com.

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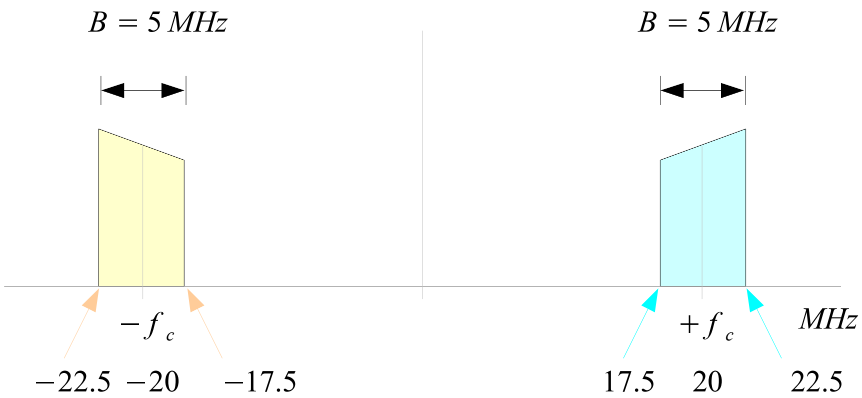
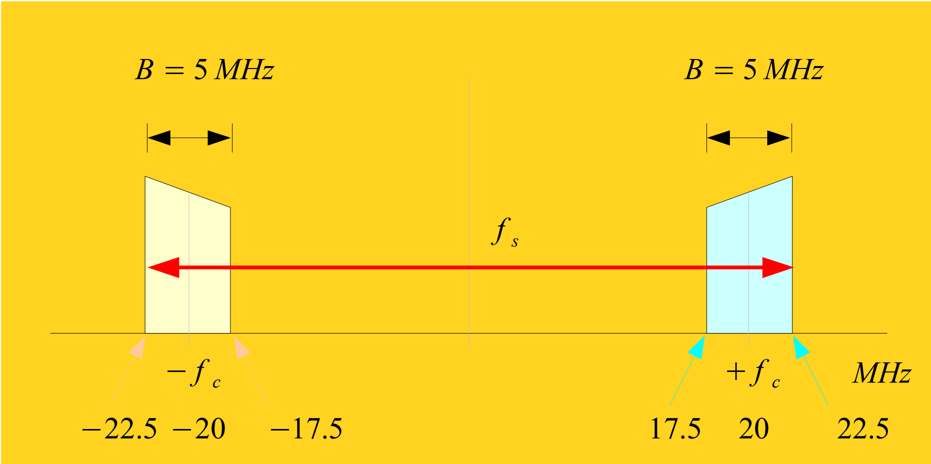
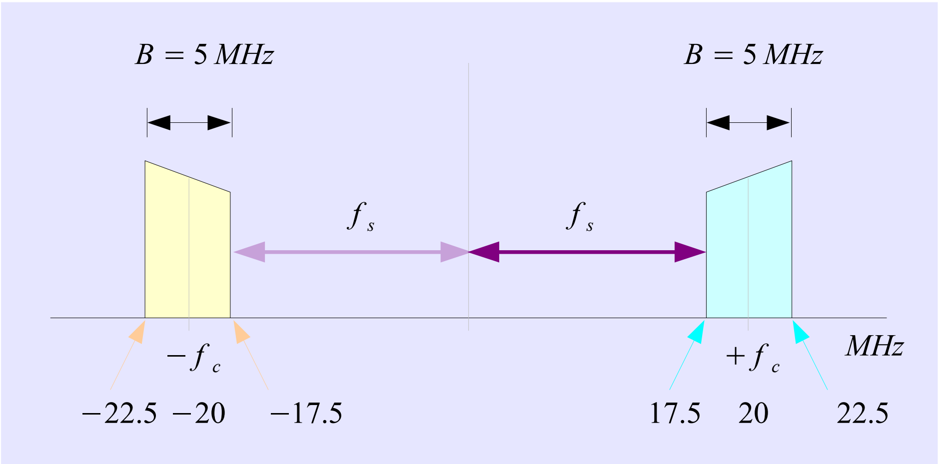
Band-limited Signal





- Lowpass Sampling

- Bandpass Sampling
- IF filtering
- Harmonic Sampling
- Sub-Nyquist Sampling



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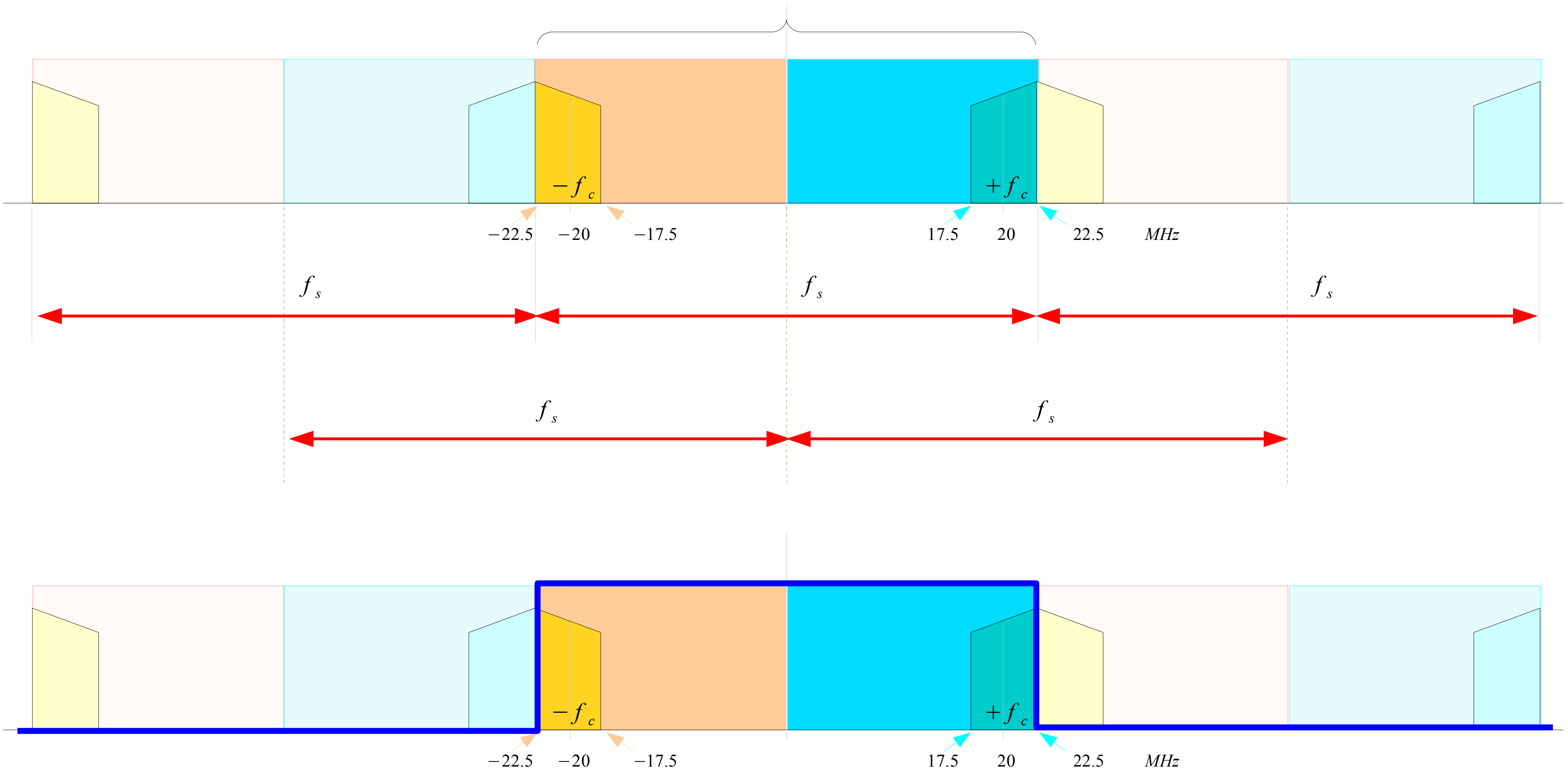
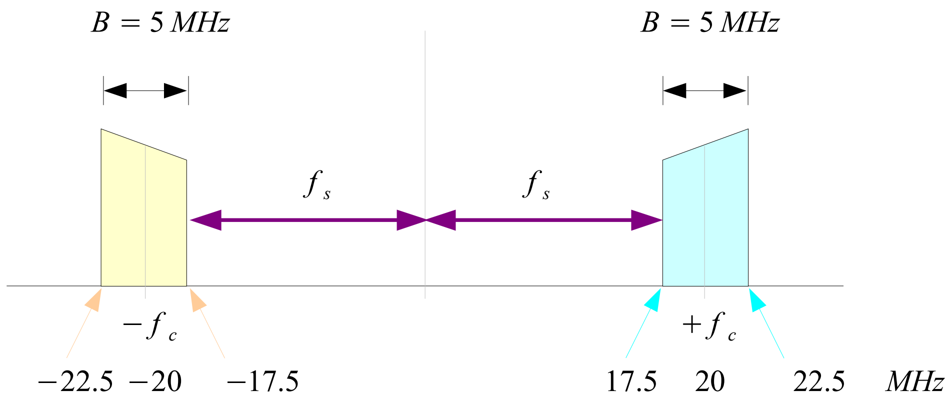
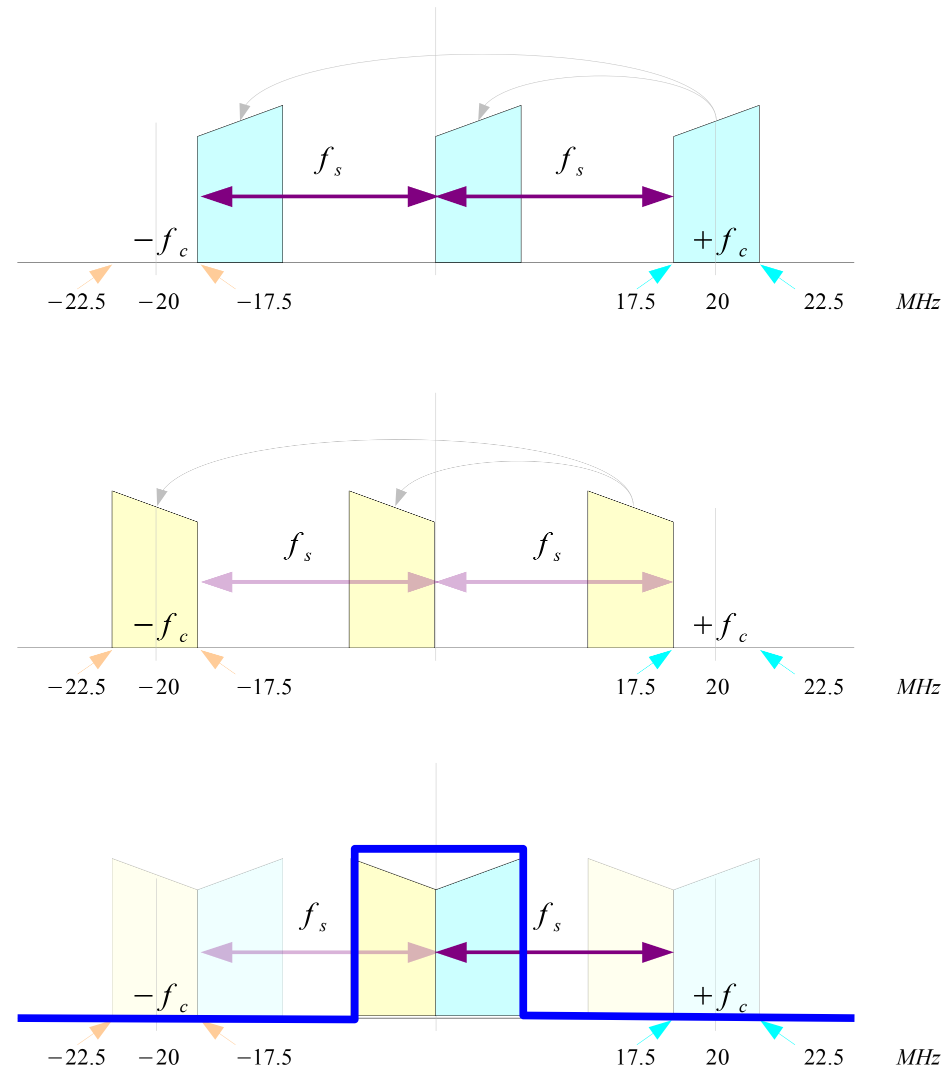
Low-pass Signal Sampling



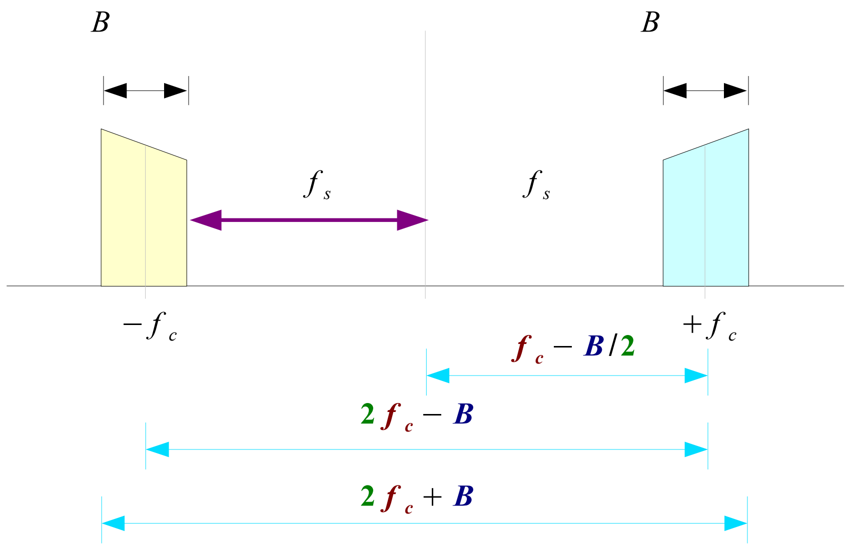
Band-pass Signal Sampling





- **Bandpass Sampling**
- **IF filtering**
- **Harmonic Sampling**
- **Sub-Nyquist Sampling**

Band-pass Signal Sampling

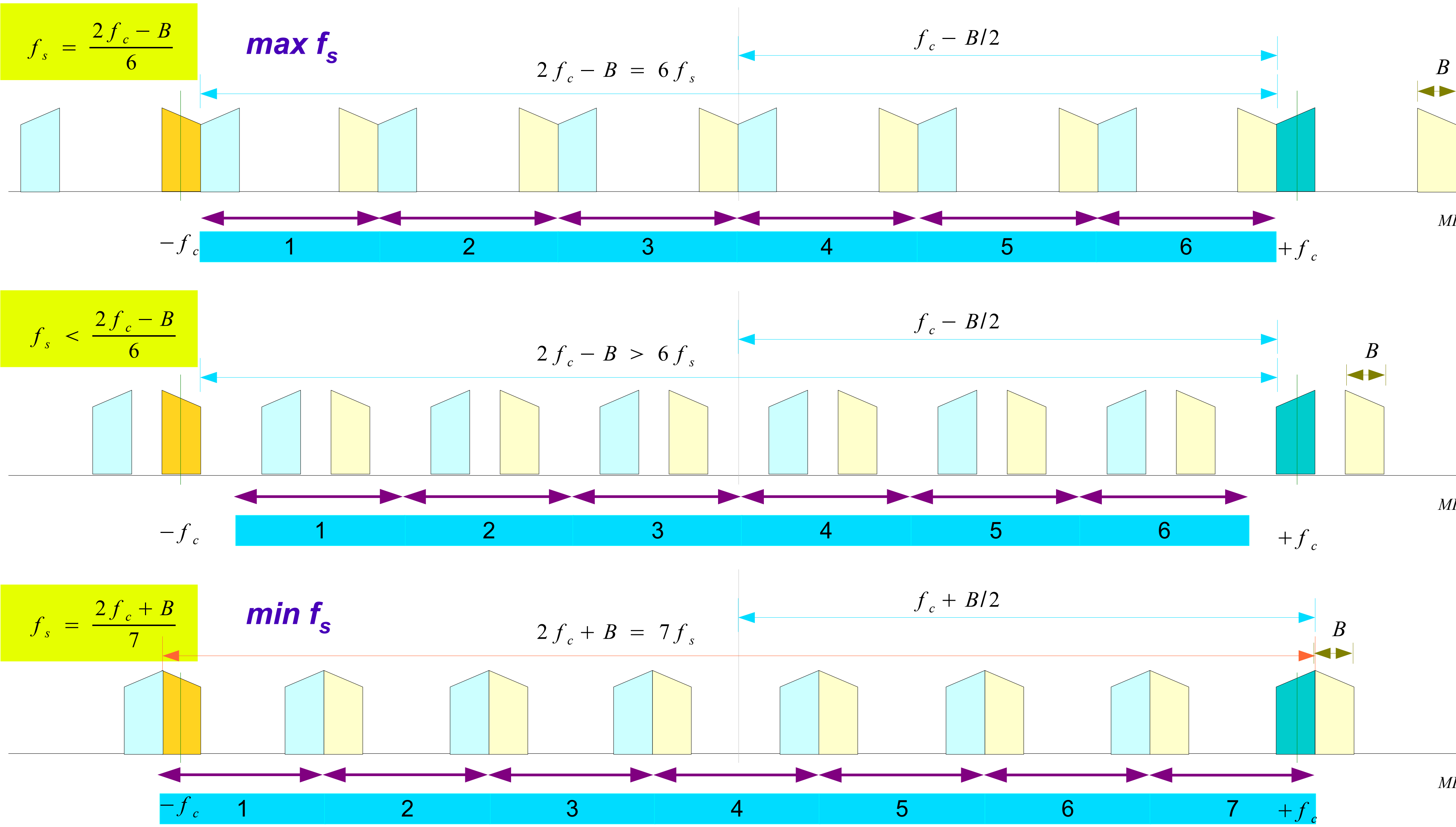


- **Bandpass Sampling**
- **IF filtering**
- **Harmonic Sampling**
- **Sub-Nyquist Sampling**

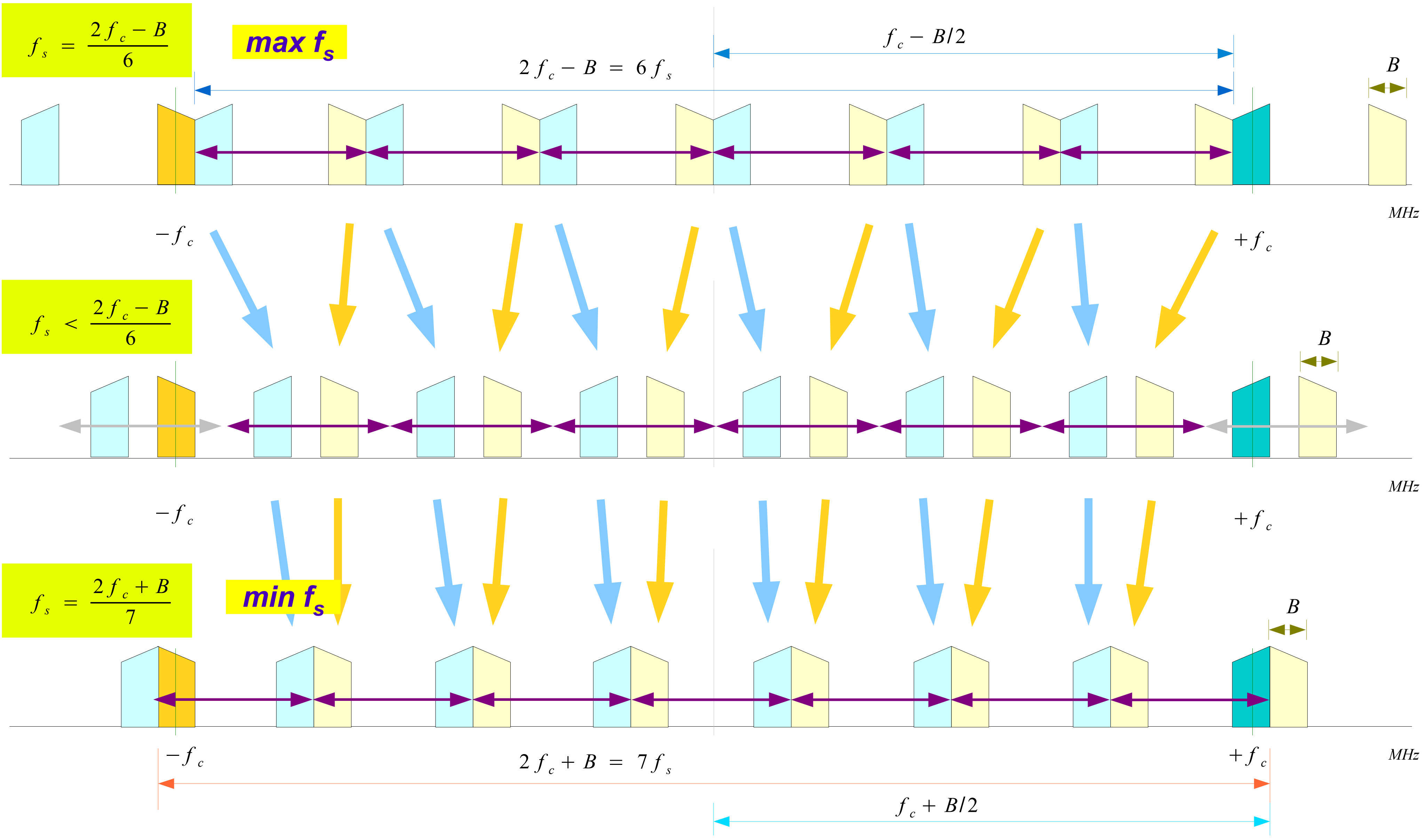
$$2f_c - B = m \cdot f_s$$ ***max f_s***

$$2f_c + B = (m+1) \cdot f_s$$ ***min f_s***

Band-pass Signal Sampling



Band-pass Signal Sampling



$$\frac{2f_c + B}{m+1} \le f_s \le \frac{2f_c - B}{m}$$

$$f_c = 20\,MHz$$
$$B = 5\,MHz$$

$$2B \le f_s$$

$$\frac{2\cdot 20 + 5}{1+1} = 22.5 \le f_s \le \frac{2\cdot 20 - 5}{1} = 35 \quad \Rightarrow \quad f_s = 22.5\,MHz \quad (10 \le f_s)$$

$$\frac{2\cdot 20 + 5}{2+1} = 15 \le f_s \le \frac{2\cdot 20 - 5}{2} = 17.5 \quad \Rightarrow \quad f_s = 17.5\,MHz \quad (10 \le f_s)$$

$$\frac{2\cdot 20 + 5}{3+1} = 11.25 \le f_s \le \frac{2\cdot 20 - 5}{3} = 11.67 \quad \Rightarrow \quad f_s = 11.25\,MHz \quad (10 \le f_s)$$

$$\frac{2\cdot 20 + 5}{4+1} = 9 \ge \frac{2\cdot 20 - 5}{4} = 8.75 \quad \Rightarrow$$ X

$$\frac{2\cdot 20 + 5}{5+1} = 7.5 \ge \frac{2\cdot 20 - 5}{5} = 7.0 \quad \Rightarrow$$ X

$$\frac{2f_c + B}{m+1} \le f_s \le \frac{2f_c - B}{m}$$

$$f_c = 20\,MHz$$
$$B = 5\,MHz$$

$$2B \le f_s$$

$$\frac{f_c + B/2}{B} = R$$

highest signal frequency / bandwidth

$$\frac{2f_c + B}{(m+1)B} = f(m, R)$$

minimum sampling rate / bandwidth

$$\frac{2(f_c + B/2)}{(m+1)B} = \frac{2R}{m+1} = f(m, R)$$

$m = 1 \quad f(1,R) = R$

$m = 2 \quad f(2,R) = \frac{2}{3}R$

$m = 3 \quad f(3,R) = \frac{1}{2}R$

$m = 4 \quad f(4,R) = \frac{2}{5}R$

$m = 5 \quad f(5,R) = \frac{1}{3}R$

$m = 6 \quad f(6,R) = \frac{2}{7}R$

$m = 7 \quad f(7,R) = \frac{1}{4}R$

$m = 8 \quad f(8,R) = \frac{2}{9}R$

$$\frac{2f_c + B}{m+1} \le f_s \le \frac{2f_c - B}{m}$$

$f_c = 20\,MHz$

$B = 5\,MHz$

$$2B \le f_s$$

$$\frac{f_c + B/2}{B} = R$$

highest signal frequency / **bandwidth**

$$f_H = f_c + B/2$$

$$R = f_H / B$$

$$\frac{2f_c + B}{m+1} \cdot \frac{1}{B} = f(m, R)$$

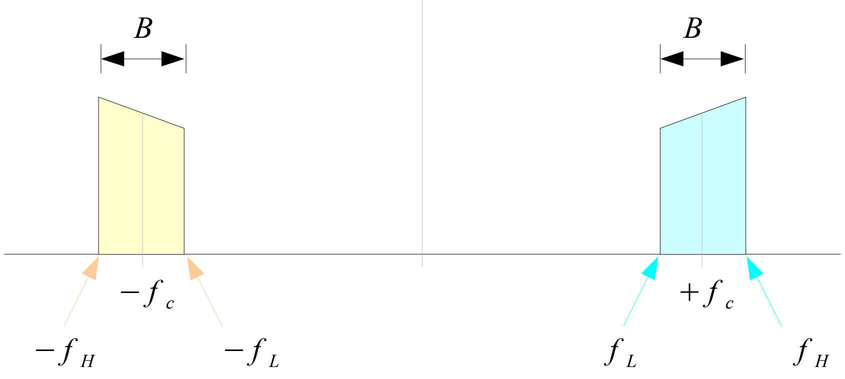
minimum sampling rate / **bandwidth**

$$f_{s,min} = \frac{2f_c + B}{m+1} = \frac{2f_H}{k}$$

$$\frac{2(f_c + B/2)}{(m+1)B} = \frac{2R}{m+1} = f(m, R)$$

$$f(m, R) = \frac{2f_H}{kB} = \frac{2R}{k}$$

$$m + 1 = k$$



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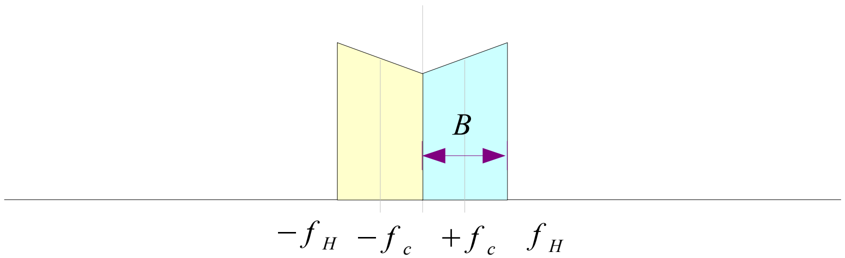
$k = 1 \quad (m = 0)$

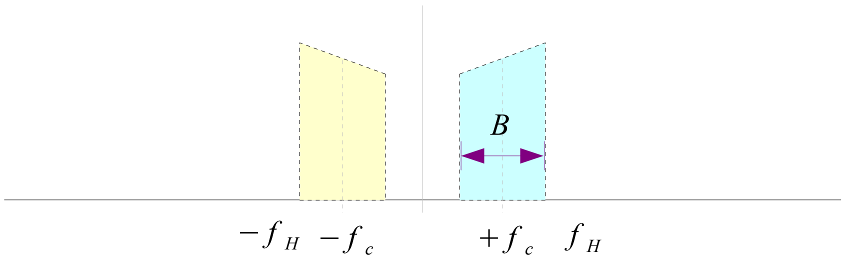


$$f_H = f_c + B/2 = 1B$$

$$f_H / B = R = 1$$

$$f_{s,min} = \frac{2f_H}{k} = \frac{2f_H}{m+1} = 2B$$

$k = 1 \quad (m = 0)$

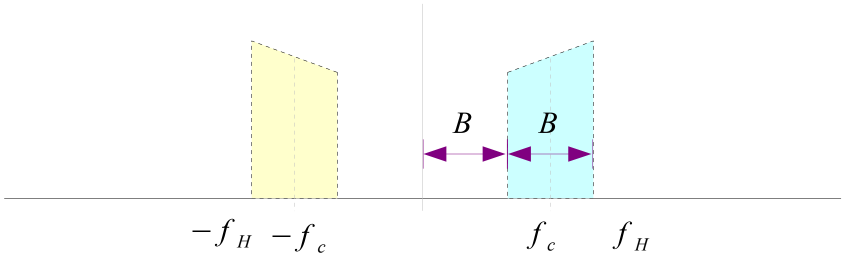


$$f_H = f_c + B/2 = 1.5B$$

$$f_H / B = R = 1.5$$

$$f_{s,min} = \frac{2f_H}{k} = \frac{2f_H}{m+1} = 3B$$

$k = 1 \quad (m = 0)$

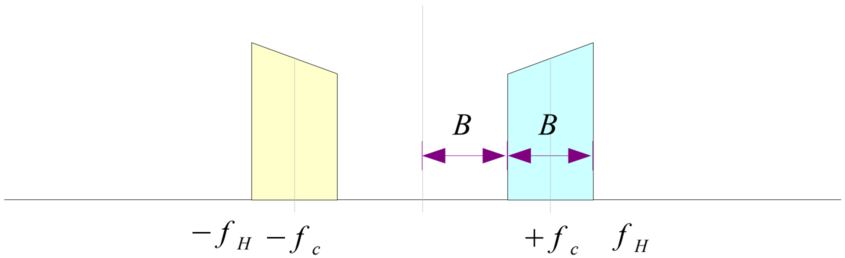


$$f_H = f_c + B/2 = 2B$$

$$f_H / B = R = 2$$

$$f_{s,min} = \frac{2f_H}{k} = \frac{2f_H}{m+1} = 4B$$

$$k = 2 \quad (m = 1)$$

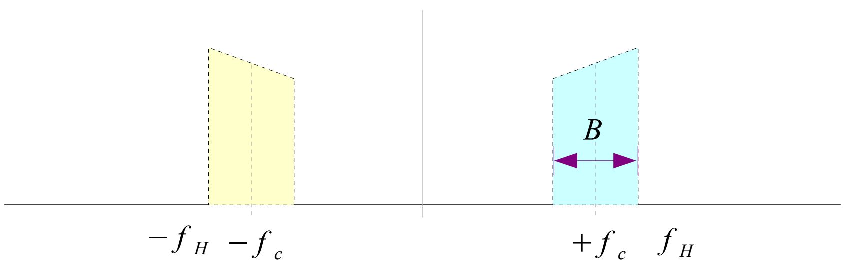


$$f_H = f_c + B/2 = 2\,B$$

$$f_H / B = R = 2$$

$$f_{s,min} = \frac{2 f_H}{k} = \frac{2 f_H}{m+1} = 2\,B$$

$$k = 2 \quad (m = 1)$$

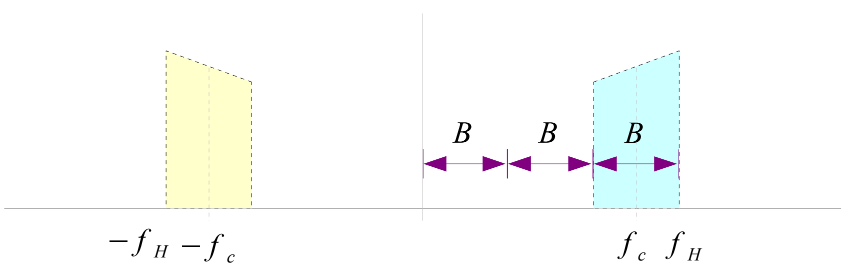


$$f_H = f_c + B/2 = 2.5\,B$$

$$f_H / B = R = 2.5$$

$$f_{s,min} = \frac{2 f_H}{k} = \frac{2 f_H}{m+1} = 2.5\,B$$

$$k = 2 \quad (m = 3)$$

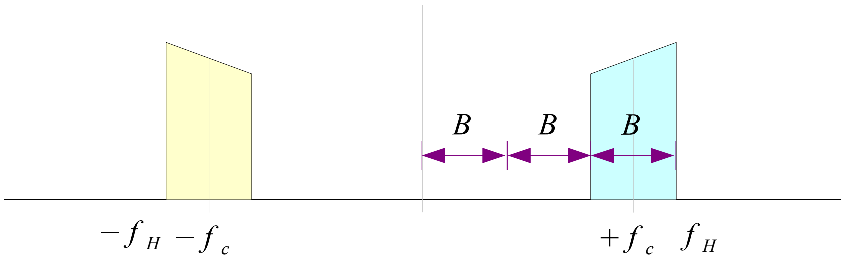


$$f_H = f_c + B/2 = 3\,B$$

$$f_H / B = R = 3$$

$$f_{s,min} = \frac{2 f_H}{k} = \frac{2 f_H}{m+1} = 3\,B$$

$$k = 3 \quad (m = 2)$$

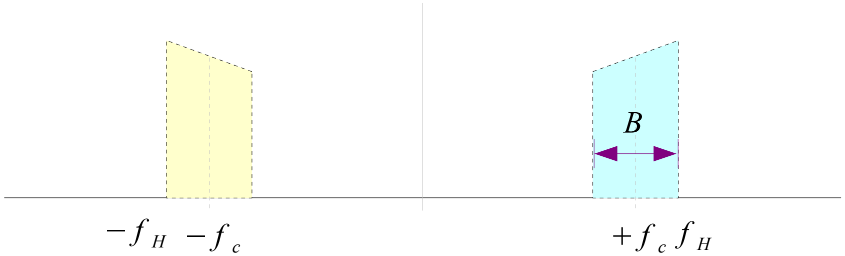


$$f_H = f_c + B/2 = 3B$$

$$f_H / B = R = 3$$

$$f_{s,min} = \frac{2 f_H}{k} = \frac{2 f_H}{m+1} = 2B$$

$$k = 3 \quad (m = 2)$$

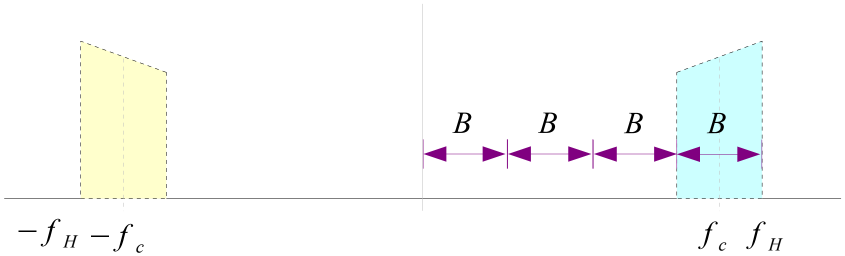


$$f_H = f_c + B/2 = 3.5B$$

$$f_H / B = R = 3.5$$

$$f_{s,min} = \frac{2 f_H}{k} = \frac{2 f_H}{m+1} = \frac{7}{3} B$$

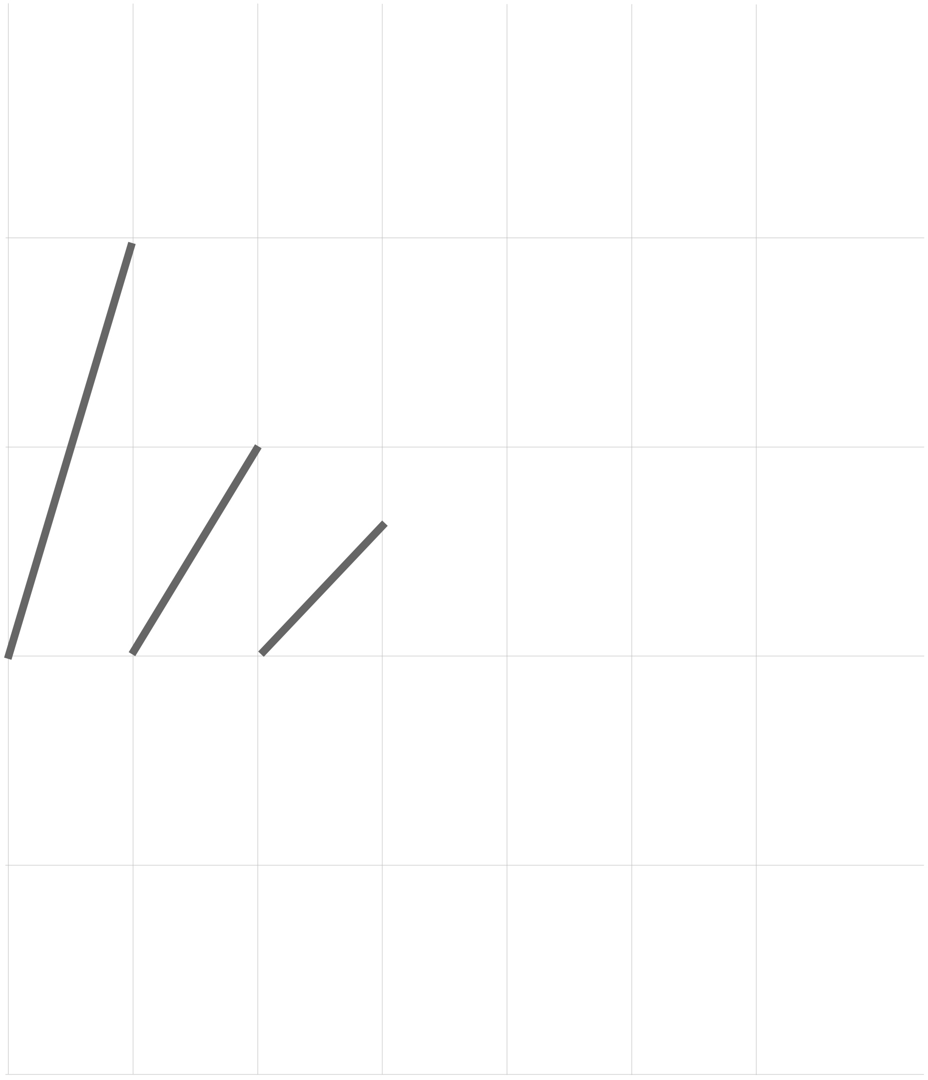
$$k = 3 \quad (m = 2)$$



$$f_H = f_c + B/2 = 4B$$

$$f_H / B = R = 4$$

$$f_{s,min} = \frac{2 f_H}{k} = \frac{2 f_H}{m+1} = \frac{8}{3} B$$



References

[1] http://en.wikipedia.org/
[2] J.H. McClellan, et al., Signal Processing First, Pearson Prentice Hall, 2003
[3] A “graphical interpretation” of the DFT and FFT, by Steve Mann
[4] R. G. Lyons, Understanding Digital Signal Processing, 1997