Homework #2

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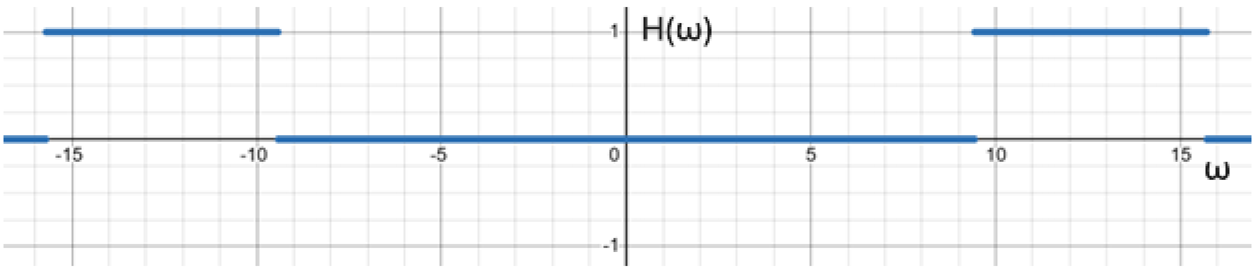
Problem #1

$\mathcal{F}(sinc(x)) = rect\left(\frac{\omega}{2\pi}\right)$, and multiplying by $2\cos(4\pi t)$ modulates this lowpass signal to be centered at ±4π on the frequency scale. Therefore, $H(\omega)$ should look like the graph below.



(a) $\mathcal{F}(x(t)) = \pi(-i\delta(\pi - \omega) + 2\delta(\omega) + \delta(\omega - 4\pi) + i\delta(\omega + \pi) + \delta(\omega + 4\pi))$
Multiplying $H(\omega)$ and $X(\omega)$ gives $Y(\omega) = \pi(\delta(\omega - 4\pi) + \delta(\omega + 4\pi))$
Taking the inverse Fourier Transform them yields $y(t) = \cos(4\pi t)$

(b) $x(t)$ is simply an impulse train with sample period $T_s = 1$, so $\omega_s = 2\pi$ and $X(\omega) = 2\pi \sum_k \delta(\omega - 2\pi k)$. Multiplying by $H(\omega)$ gives $Y(\omega) = 2\pi(\delta(\omega - 4\pi) + \delta(\omega + 4\pi) + \delta(\omega - 5\pi) + \delta(\omega + 5\pi) + \delta(\omega - 3\pi) + \delta(\omega + 3\pi))$. Taking the inverse Fourier Transform then yields $y(t) = 2\big(\cos(3\pi t) + \cos(4\pi t) + \cos(5\pi t)\big)$.

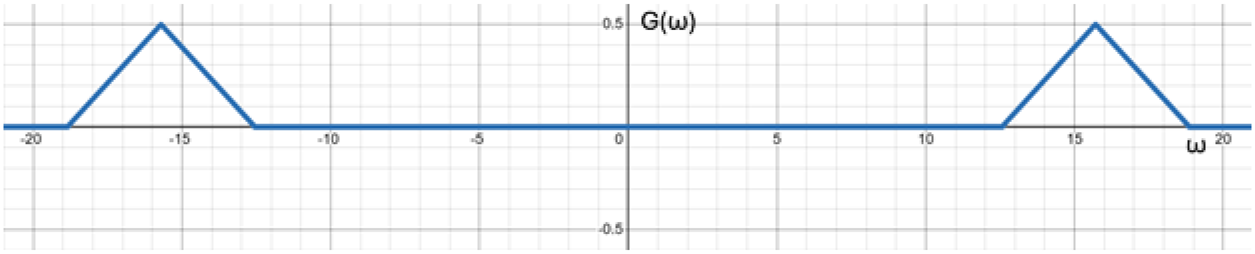
Problem #2

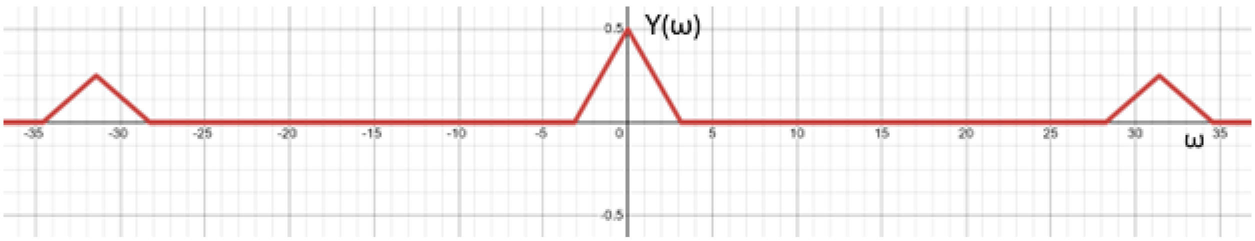
i. This is a low-pass filter with $h(t) = \frac{1}{2\pi}\int_{-3\pi}^{3\pi} j\omega e^{j\omega t} d\omega = \frac{6\pi t \cdot \cos(3\pi t) - 2\sin(3\pi t)}{2\pi t^2}$.

ii.

1. For signals with $\omega_{max} \leq 3\pi$, this filter simply calculates the derivative of the input, so $y(t) = \frac{d}{dt}x(t) = \frac{d}{dt}A \cdot \cos(2\pi t + \theta) = -2\pi A \cdot \sin(2\pi t + \theta)$. This is verified by looking at $X(\omega) = \frac{A}{2}\left[e^{j\theta}\delta(\omega - 2\pi) + e^{-j\theta}\delta(\omega + 2\pi)\right]$, which represents a single tone at ±2π. This is inside the range of our low-pass filter, so the signal is not attenuated.
2. $X(\omega) = \frac{A}{2}\left[e^{j\theta}\delta(\omega - 4\pi) + e^{-j\theta}\delta(\omega + 4\pi)\right]$, which is completely outside the range of the low-pass filter, so this signal is completely attenuated, and $y(t) = 0$.

Problem #3





Problem #4

(a) Multiplying by a rectangular pulse train with period T and width τ in the time domain is equivalent to convolving with a sinc function train in the frequency domain with period $\frac{2\pi}{T}$ and width $\frac{\pi}{\tau}$. To recover $x(t)$ from $y(t)$, we must not have any overlap between each distorted replica of $x(t)$ in the frequency domain. We can ignore the distortion effects of this filter for now. The convolution process with $c(t)$ widens the bandwidth of $x(t)$ by $\frac{\pi}{\tau}$, so we must have $\omega_{max} + \frac{\pi}{\tau} < \frac{2\pi}{T} - \frac{\pi}{\tau} - \omega_{max} \rightarrow \omega_{max} < \frac{\pi}{T} - \frac{\pi}{\tau}$. Therefore $X(\omega)$ cannot contain any frequencies greater than $\frac{\pi}{T} - \frac{\pi}{\tau}$.

(b) The cutoff frequency should be $\omega_c = \frac{\pi}{T}$ and the gain should be $\frac{1}{\tau}$.

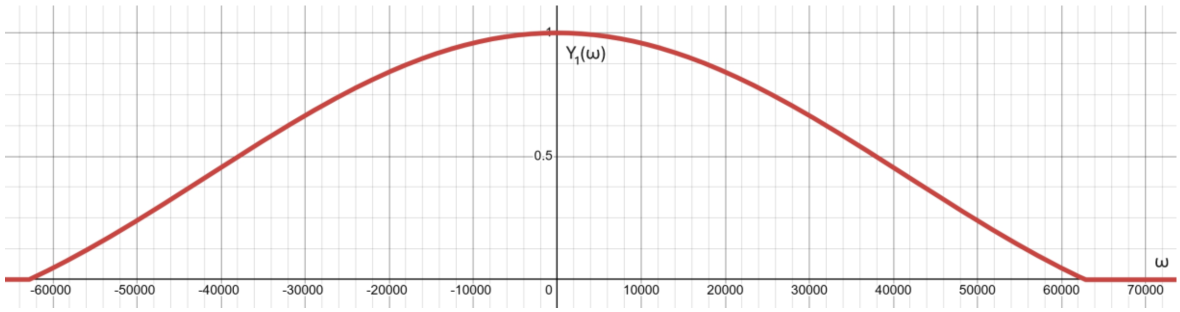
Problem #5

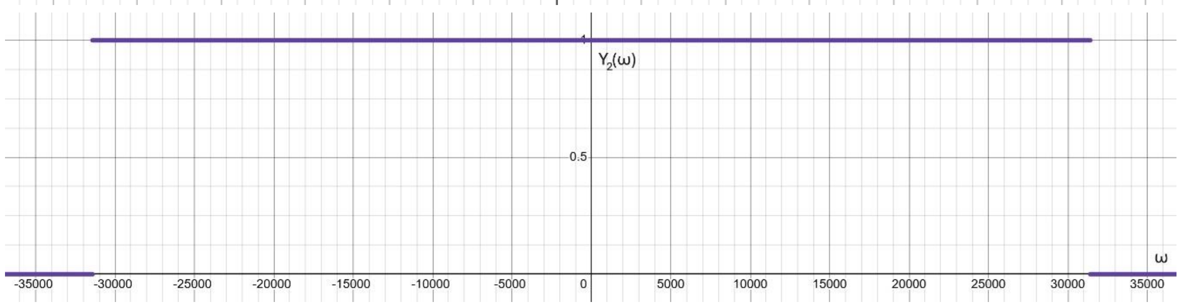
$$y(t) \cdot \cos(\omega_c t + \phi) = x(t) \cdot \cos(\omega_c t) \cdot \cos(\omega_c t + \phi) = x(t) \cdot \frac{\cos(2\omega_c t + \phi) + \cos(\phi)}{2}$$

The ideal low-pass filter then removes the $\cos(2\omega_c t + \phi)$ modulator because $\omega_c > \omega_m$ and amplifies the resulting signal by 2, giving $z(t) = x(t) \cdot \cos(\phi)$. This shows how phase offset impacts the retrieved signal. When $\phi = 0$, there is no phase offset, and the resulting signal is an exact replica of $x(t)$. If $\frac{\pi}{2} > \phi > 0$, then the recovered signal is attenuated by $\cos(\phi)$. When $\phi = \frac{\pi}{2}$, the original signal is totally lost because $\cos\left(\frac{\pi}{2}\right) = 0$. Once $\phi > \frac{\pi}{2}$, the signal becomes inverted, eventually peaking at $\phi = \pi$ and then begins oscillating back towards the initial condition when $\phi = 0$. This cycle repeats indefinitely.

Problem #6

(a)





(b) $Y_2(\omega)$ is a low-pass filter with a single-sided bandwidth of 1000π, and $Y_1(\omega)$ has a max frequency of 2000π, so the cutoff point happens at 1000π and $y(t)$ has a single-sided bandwidth of 1000π.

Problem #7

i.

(a) $x(t) \cdot x(t) \Leftrightarrow X(\omega) * X(\omega)$. This process effectively doubles the bandwidth of $x(t)$ to $(-2\omega_B, 2\omega_B)$, so we must have a Nyquist sampling rate that follows $\omega_s \geq 4\omega_B$.

(b) $\frac{d}{dt}x(t) \Leftrightarrow j\omega X(\omega)$. This doesn't change the bandwidth of $x(t)$, so $\omega_s \geq 2\omega_B$.

ii. $x_1(t) \cdot x_2(t) \Leftrightarrow X_1(\omega) * X_2(\omega)$. This sums their bandwidths, creating a signal with new frequency range $(-\omega_1 - \omega_2, \omega_1 + \omega_2)$, so we must have sample rate $\omega_s \geq 2(\omega_1 + \omega_2)$.

iii. Some cursory analysis shows that $\omega_0 = 1000\pi$ produces the desired sequence with a sampling rate of $T_s = 10^{-3}sec$. This is because $1000\pi \cdot 10^{-3}sec = \pi\ rad/s$. Adding or subtracting multiples of 2000π from ω_0 shifts this angular frequency by $2\pi\ rad/s$, so other distinct values of ω_0 that work are $\omega_0 = 3000\pi$ and $\omega_0 = 5000\pi$.

Problem #8

(a)

(b)

Problem #9

(a) $\frac{\sin(1000\pi t)}{\pi t}$ has a maximum of 1000 at $t = 0$. Therefore, over modulation occurs for any values of $A < 1000$. So, in order to use envelope detection, we must have $A \geq 1000$, with a minimum of $A = 1000$.

(b) $m = \frac{max|m(t)|}{A} = \frac{1000}{1000} = 1 = 100\%$