Filter Dispersion

Any signal that carries significant **information** must has some non-zero **bandwidth**. In other words, the signal energy (as well as the information it carries) is **spread** across many frequencies.

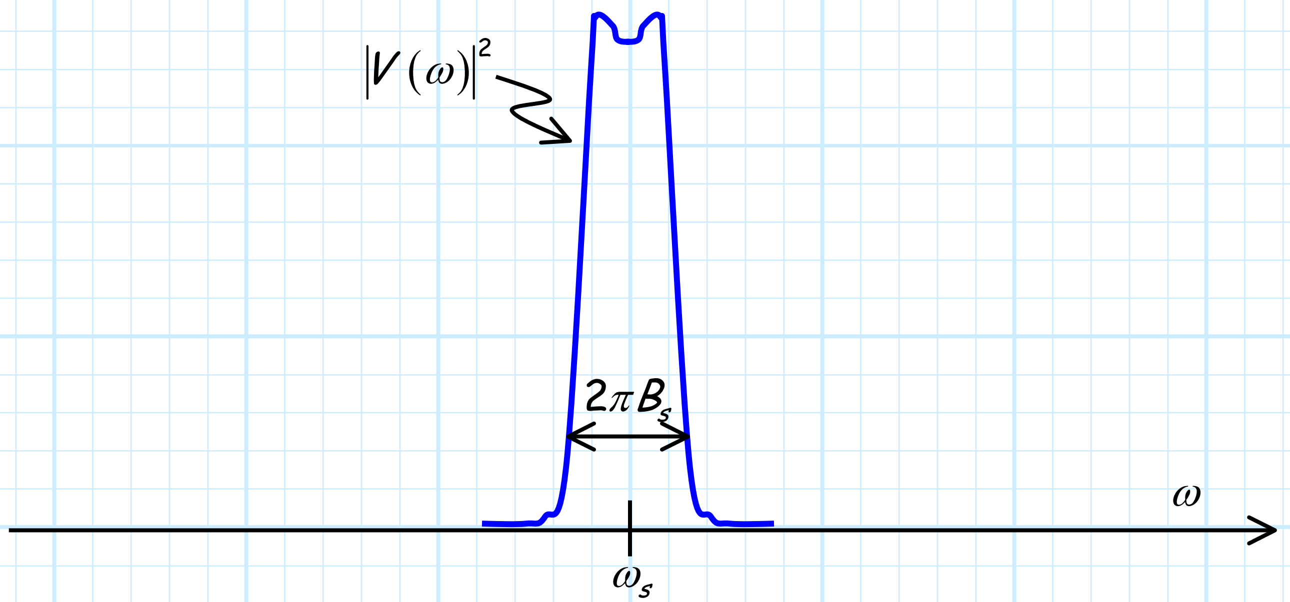
If the different frequencies that comprise a signal propagate at different velocities through a microwave filter (i.e., each signal frequency has a different delay τ), the output signal will be **distorted**. We call this phenomenon signal **dispersion**.

Q: *I see! The phase delay $\tau(\omega)$ of a filter **must** be a constant with respect to frequency—otherwise signal dispersion (and thus signal distortion) will result. Right?*

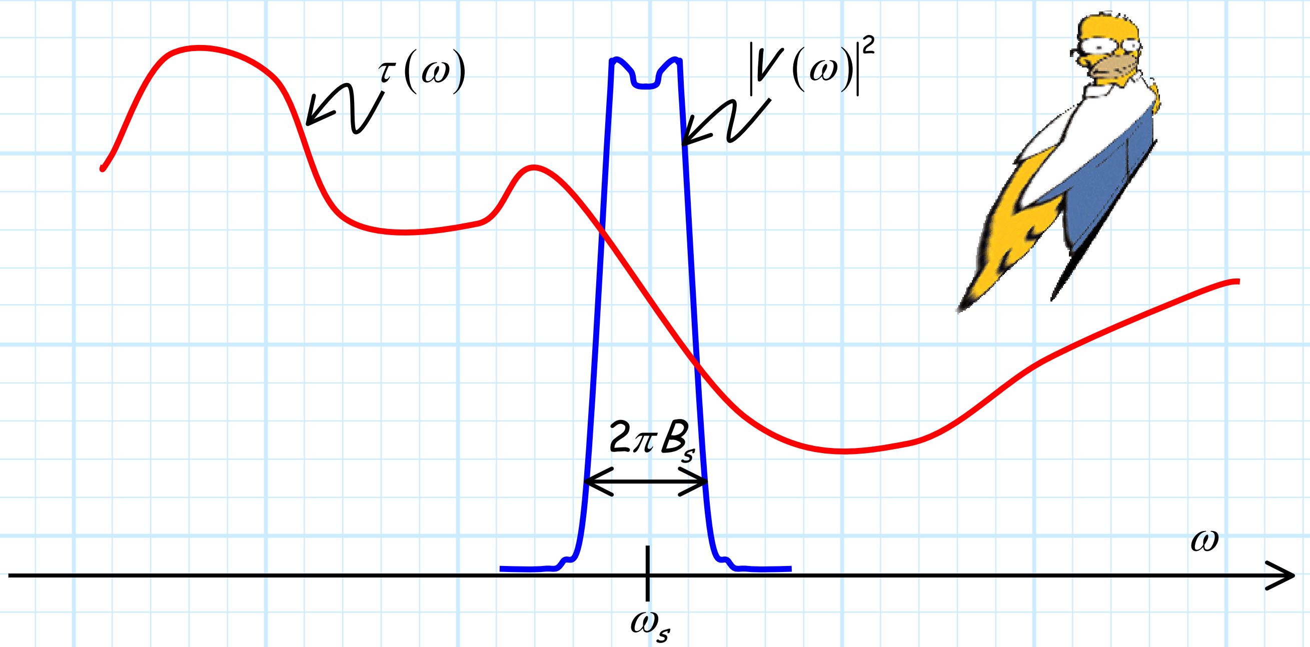
A: Not necessarily! Although a constant phase delay will **insure** that the output signal is not distorted, it is **not** strictly a requirement for that happy event to occur.

This is a **good** thing, for as we shall latter see, building a good filter with a constant phase delay is **very** difficult!

For example, consider a modulated signal with the following frequency **spectrum**, exhibiting a **bandwidth** of B_s Hertz.



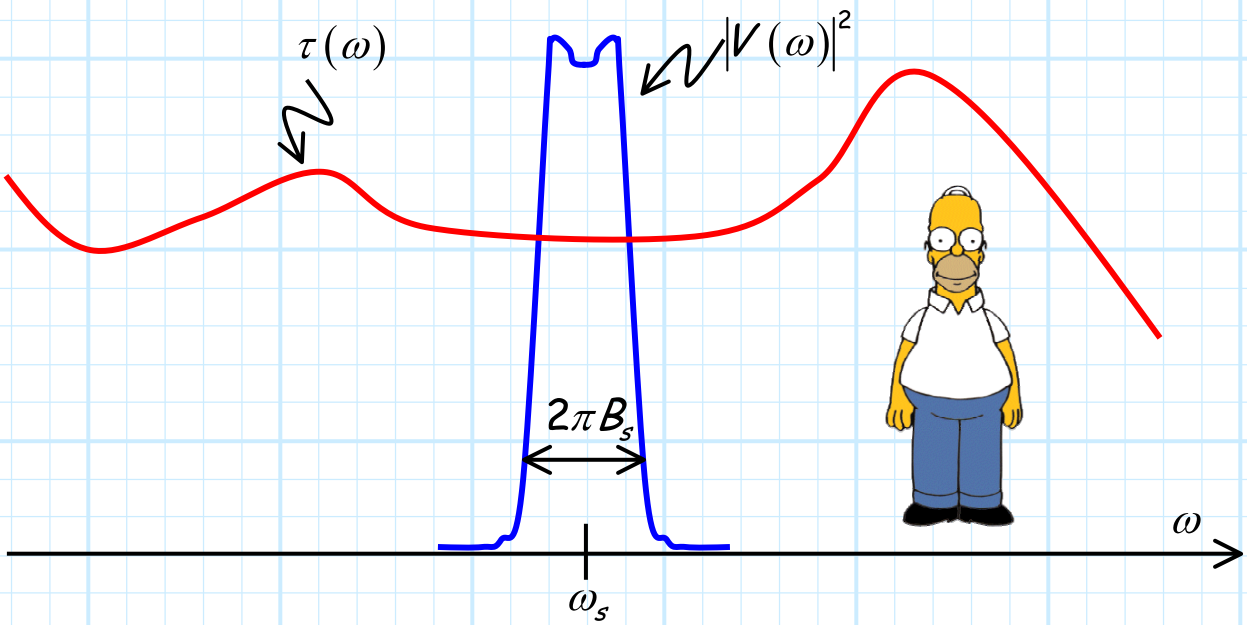
Now, let's likewise plot the **phase delay** function $\tau(\omega)$ of some filter:



Note that for this case the filter phase delay is **nowhere** near a constant with respect to frequency.

However, this fact alone does **not** necessarily mean that our signal would suffer from **dispersion** if it passed through this filter. Indeed, the signal in this case **would** be distorted, but **only** because the phase delay $\tau(\omega)$ changes significantly across the **bandwidth** B_s of the signal.

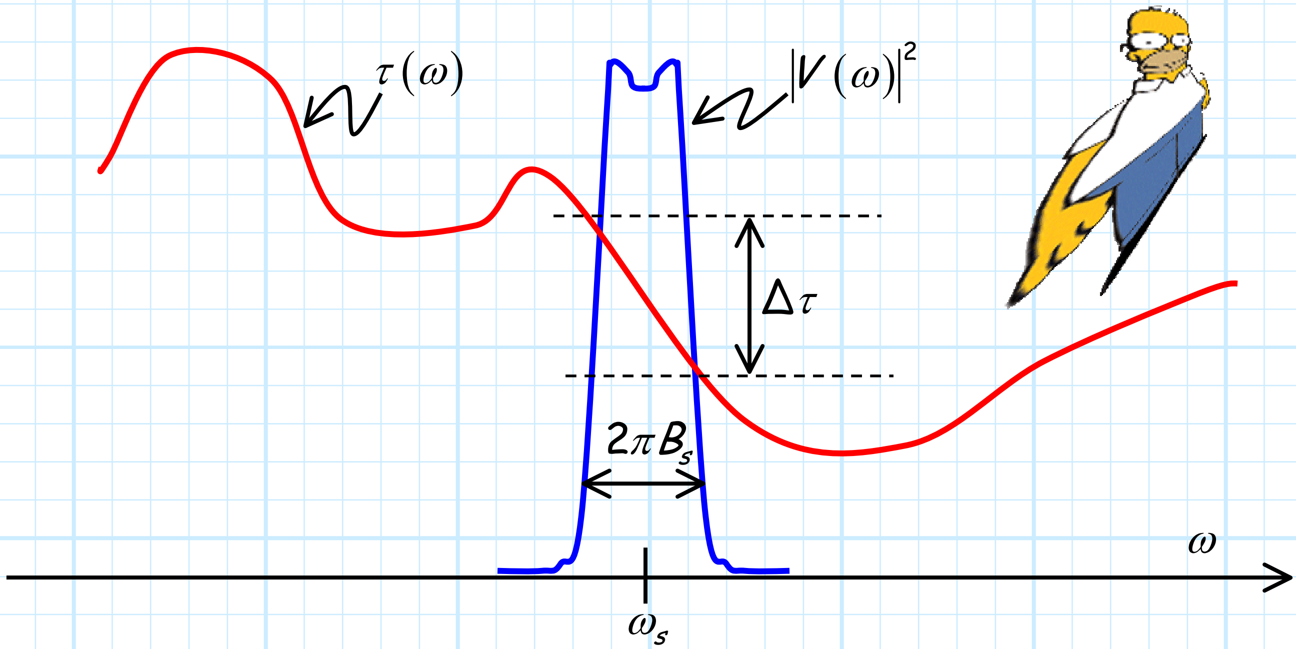
Conversely, consider this **phase delay**:



As with the previous case, the phase delay of the filter is **not** a constant. Yet, if this signal were to pass through this filter, it would **not** be distorted!

The reason for this is that the phase delay across the **signal bandwidth** is approximately constant—each frequency component of the **signal** will be delayed by the **same** amount.

Compare this to the **previous** case, where the phase delay changes by a precipitous value $\Delta\tau$ across signal bandwidth B_s:



Now **this** is a case where dispersion **will** result!

Q: *So does $\Delta\tau$ need to be **precisely** zero for no signal distortion to occur, or is there some **minimum** amount $\Delta\tau$ that is acceptable?*

A: Mathematically, we find that dispersion will be **insignificant** if:

$$\omega_s \Delta\tau \ll 1$$

A more specific (but **subjective**) "rule of thumb" is:

$$\omega_s \Delta\tau < \frac{\pi}{5}$$

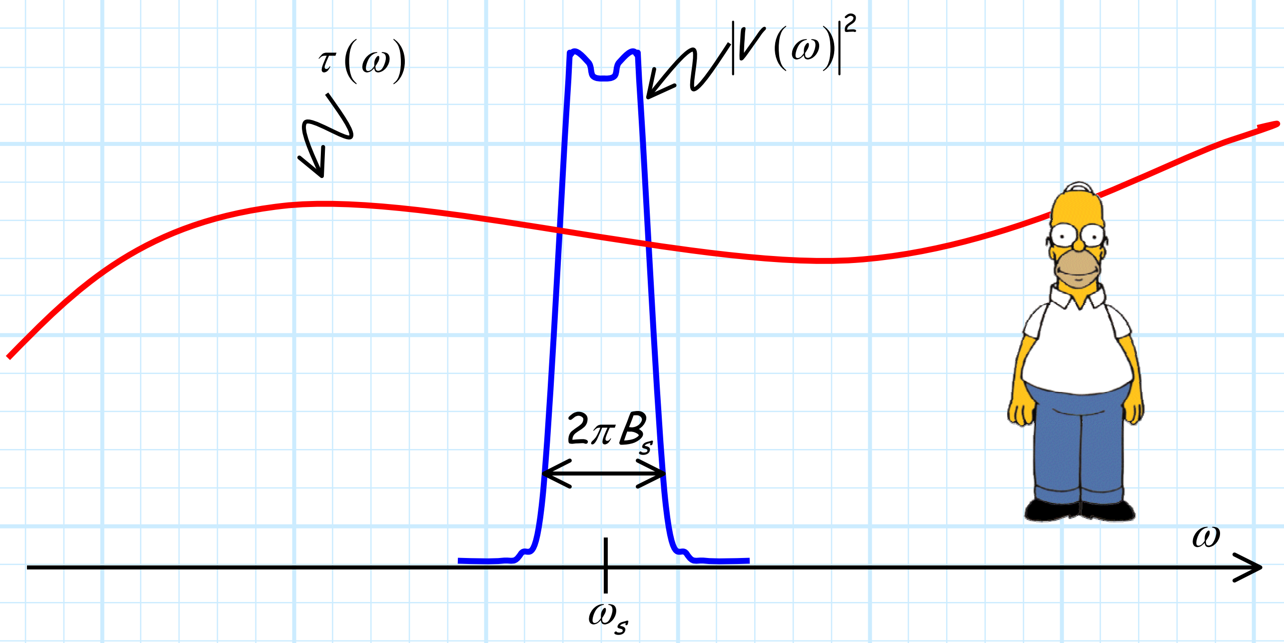
Or, using $\omega_s = 2\pi f_s$:

$$f_s \Delta\tau < 0.1$$

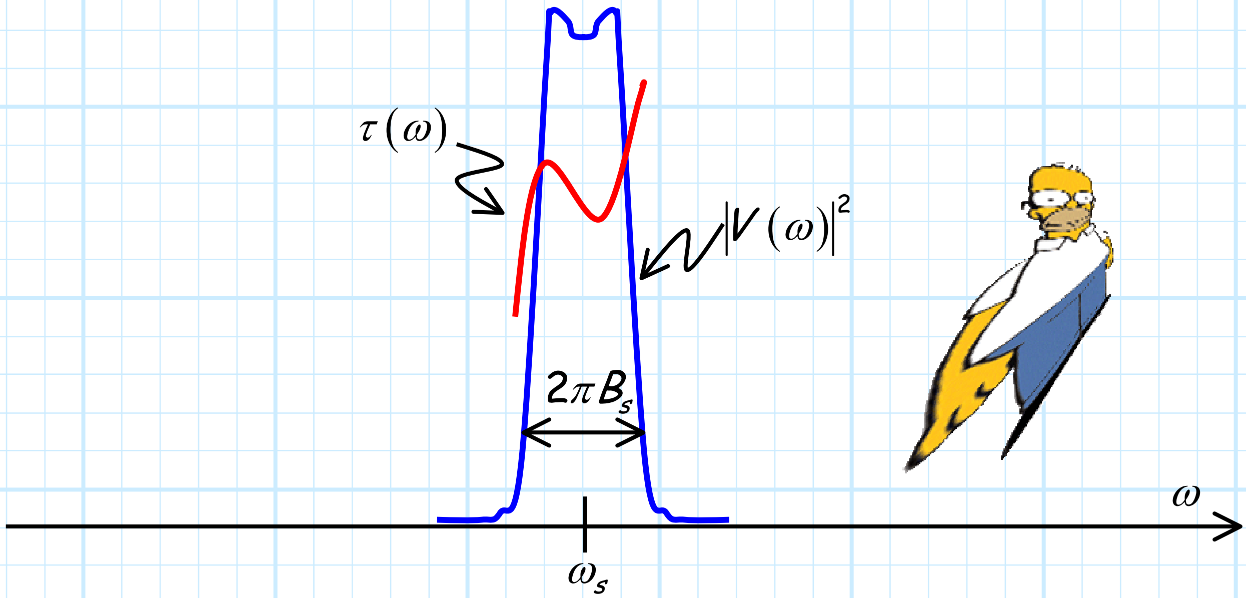
Generally speaking, we find for **wideband** filters—where filter bandwidth B is much greater than the signal bandwidth (i.e., $B \gg B_s$)—the above criteria is **easily** satisfied. In other words, signal dispersion is **not** typically a problem for wide band filters (e.g., preselector filters).

This is **not** to say that $\tau(\omega)$ is a constant for wide band filters. Instead, the phase delay can change **significantly** across the wide **filter** bandwith.

What we typically find however, is that the function $\tau(\omega)$ does not change very **rapidly** across the wide filter bandwidth. As a result, the phase delay will be **approximately** constant across the relatively narrow signal bandwidth B_s.



Conversely, a **narrowband** filter—where filter bandwidth B is approximately **equal** to the signal bandwidth (i.e., $B_s \approx B$)—can (if we're not careful!) exhibit a phase delay which likewise changes **significantly** over **filter** bandwidth B. This means of course that it **also** changes significantly over the **signal** bandwidth B_s!



Thus, a **narrowband** filter (e.g., IF filter) must exhibit a **near constant** phase delay $\tau(\omega)$ in order to **avoid** distortion due to signal dispersion!