Any signal that carries significant information must have 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 $\tau$), 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 bandwidth.

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 $B_s$. 

![Diagram of phase delay and magnitude]

- $\tau(\omega)$
- $|V(\omega)|^2$
- $2\pi B_s$
- $\omega_s$
- $\omega$
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!