Filter Dispersion

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 τ), the output signal will be **distorted**.

→ We call this phenomenon signal **dispersion**.

It doesn't have to be *precisely* constant!

Q: *I **think** 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**!

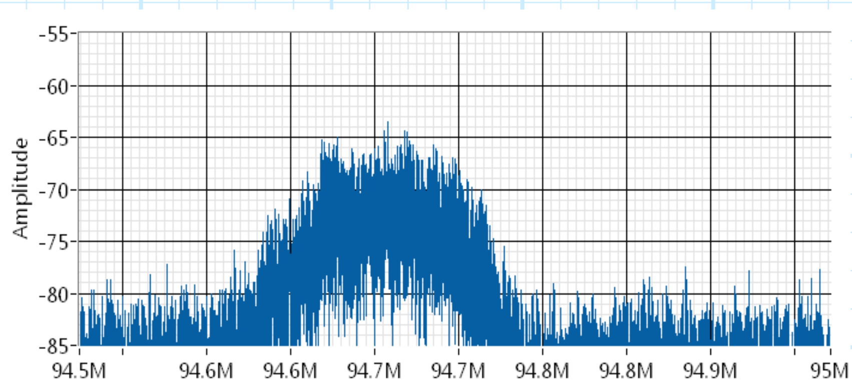
Although a constant phase delay will **insure** that the output signal is not distorted, it is **not strictly** a requirement for that **happy event** to occur.

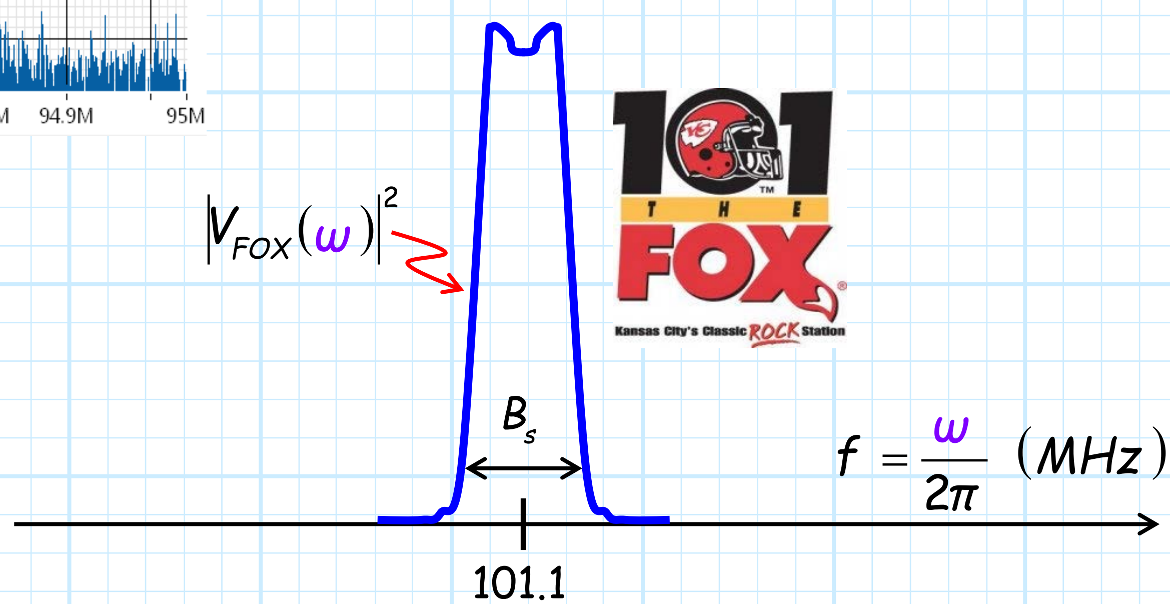
This is a **good** thing, for as we shall latter see, building a good filter with a constant phase delay is **very** difficult!

A modulated signal has a non-zero bandwidth

For **example**, consider a modulated signal with the following frequency **spectrum**, exhibiting a **bandwidth** of B_s (e.g.,$B_s = 200kHz$ for FM radio):

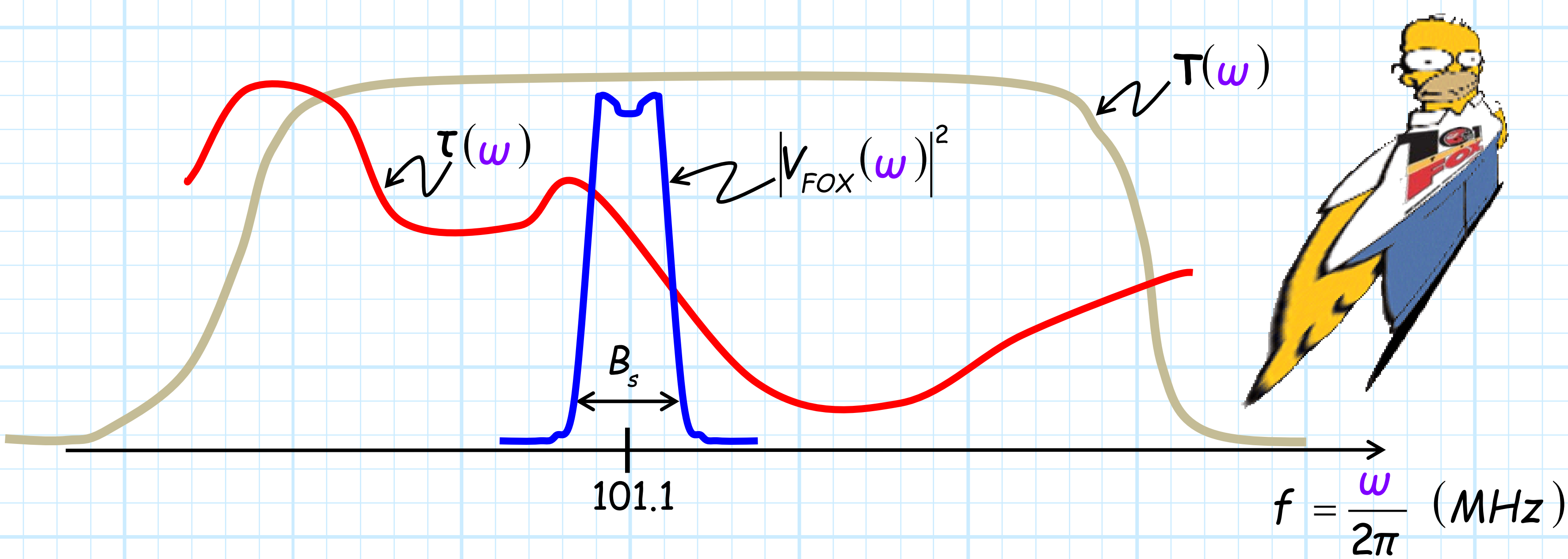
http://www.ni.com/white-paper/13193/en/





This FM signal would be distorted

Now, let's likewise plot the **phase delay** function $\tau(\omega)$ of some **filter** with transmission function $\mathbf{T}(\omega)$:

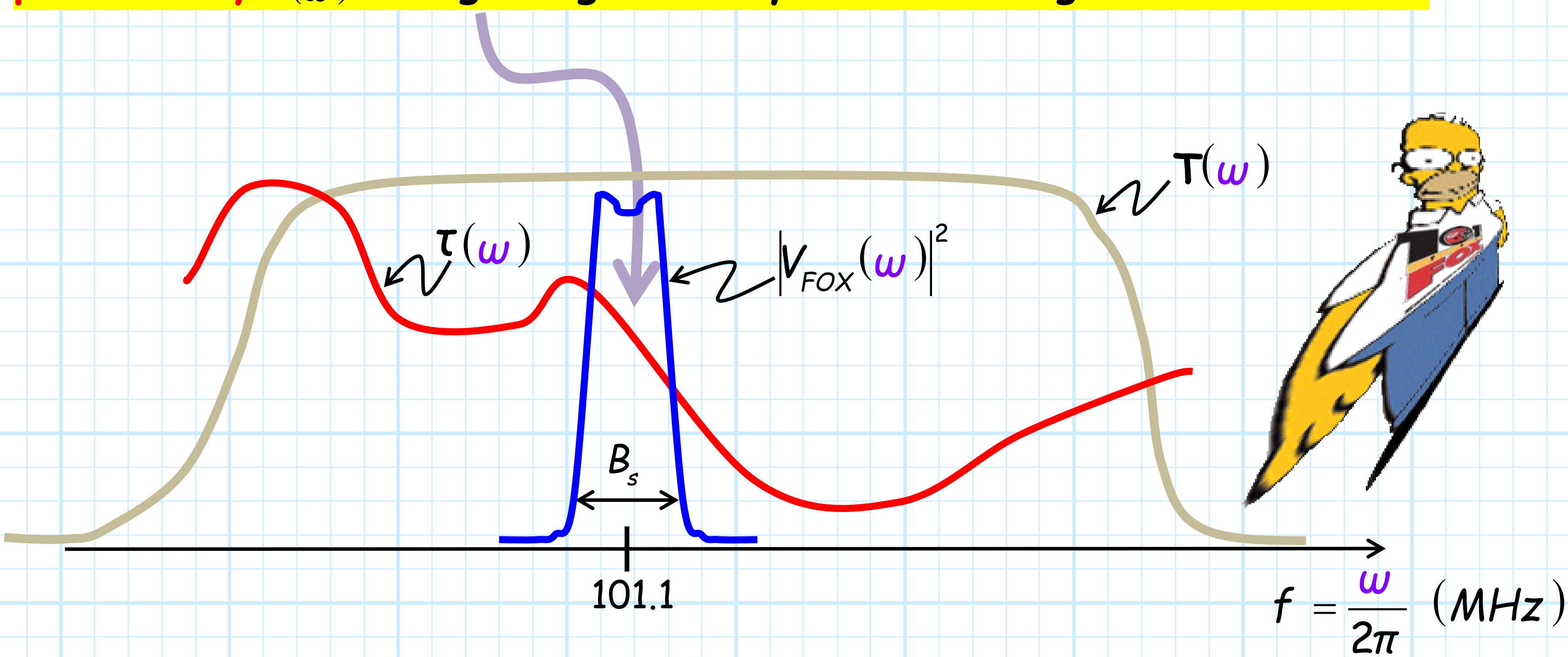


→ Note that for this case the filter **phase delay** is **nowhere** near a **constant** with respect to frequency.

Delay is not constant across the *signal* bandwidth

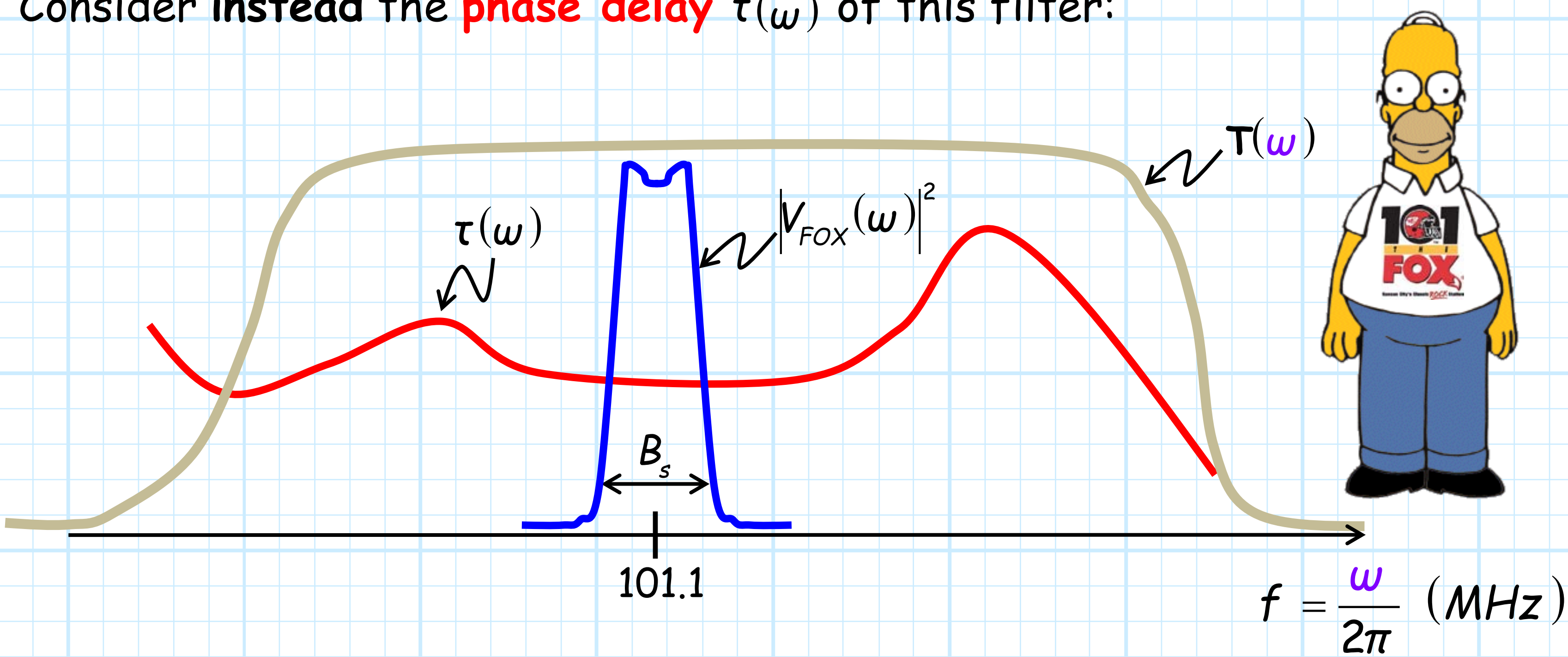
However, a non-constant phase delay does **not necessarily** mean that our signal would suffer from **dispersion** if it passed through this filter.

Indeed, the signal in this case **would** be distorted, but **only** because the **phase delay** $\tau(\omega)$ **changes significantly** across the **signal** bandwidth B_s .



Not constant across *filter* bandwidth, yet signal is not distorted

Consider **instead** the **phase delay** $\tau(\omega)$ of this filter:



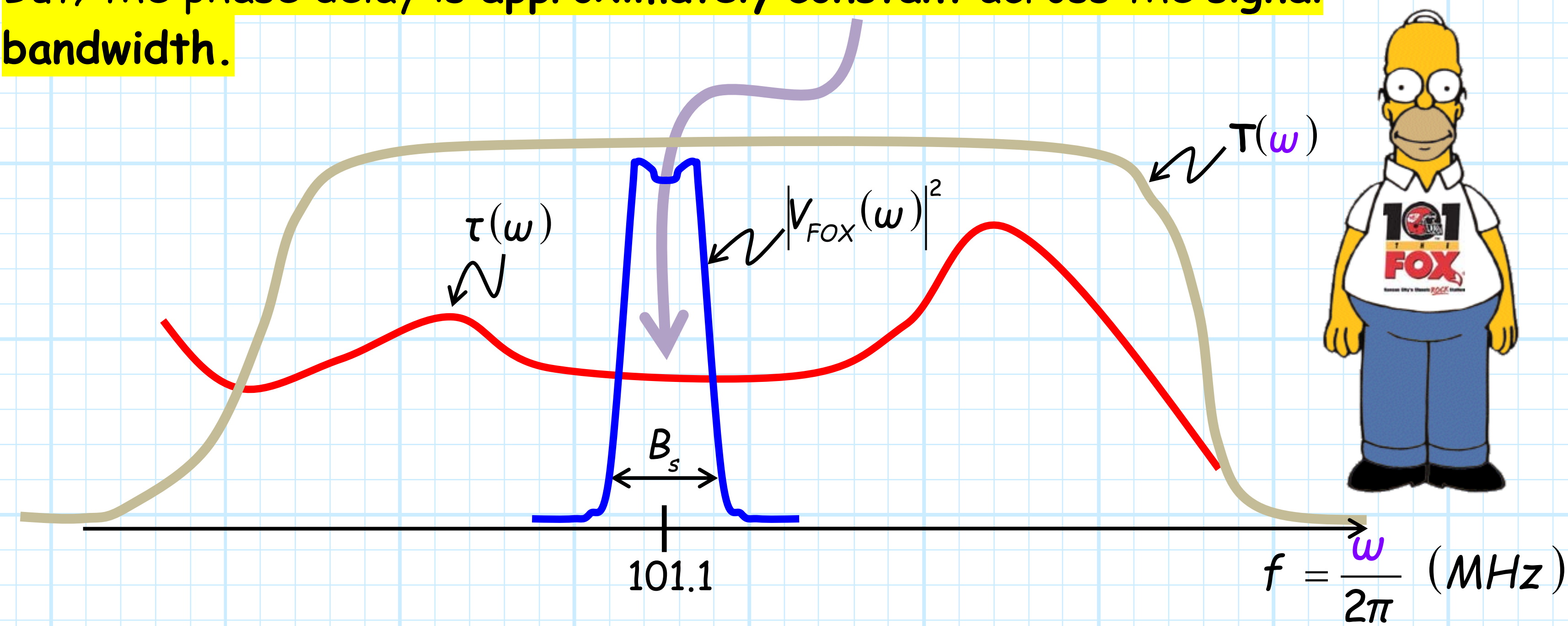
→If this FM signal were to pass through **this** filter, it would **not** be distorted!

Q: ***Not*** *distorted!? How is* ***that*** *possible—the phase delay is* ***clearly not constant*** *across the filter passband?*

It just needs to be approximately constant across the *signal* bandwidth

A: True; the **phase delay** $\tau(\omega)$ is not a constant across the **filter** bandwidth.

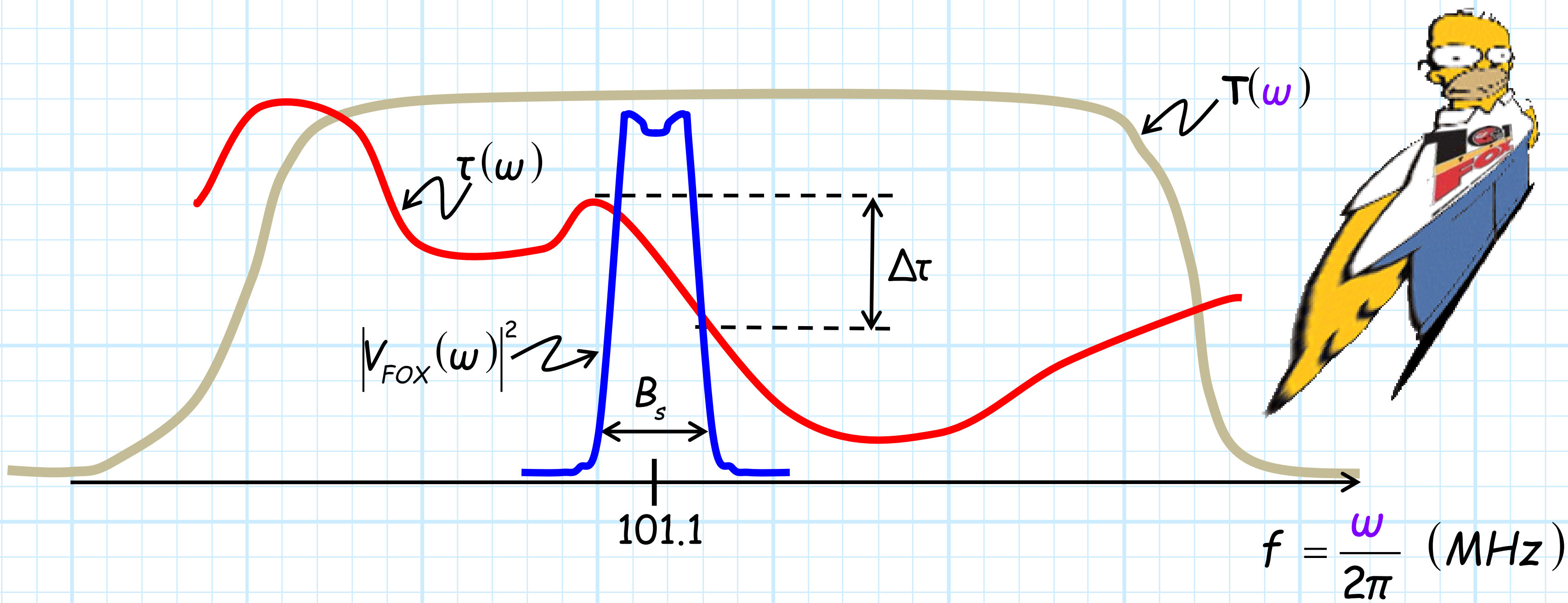
But; the phase delay is **approximately constant** across the **signal bandwidth.**



This lack of distortion is because each frequency component of the **signal** will be delayed by approximately the **same** amount.

Constant across neither signal nor filter bandwidths

Contrast this to the **first** 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!

"Constant" and "distortion" are subjective terms

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:

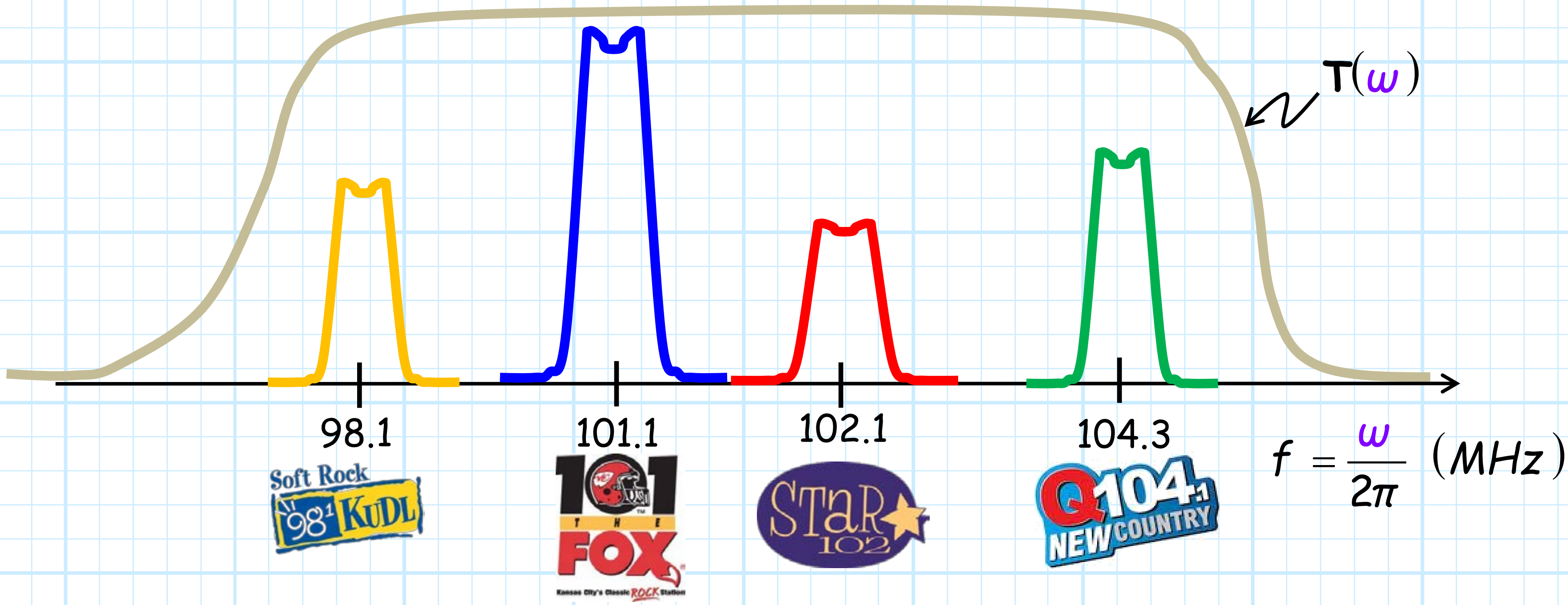
$$B_s \, \Delta\tau \ll 1$$

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

$$\boxed{B_s \, \Delta\tau < 0.1}$$

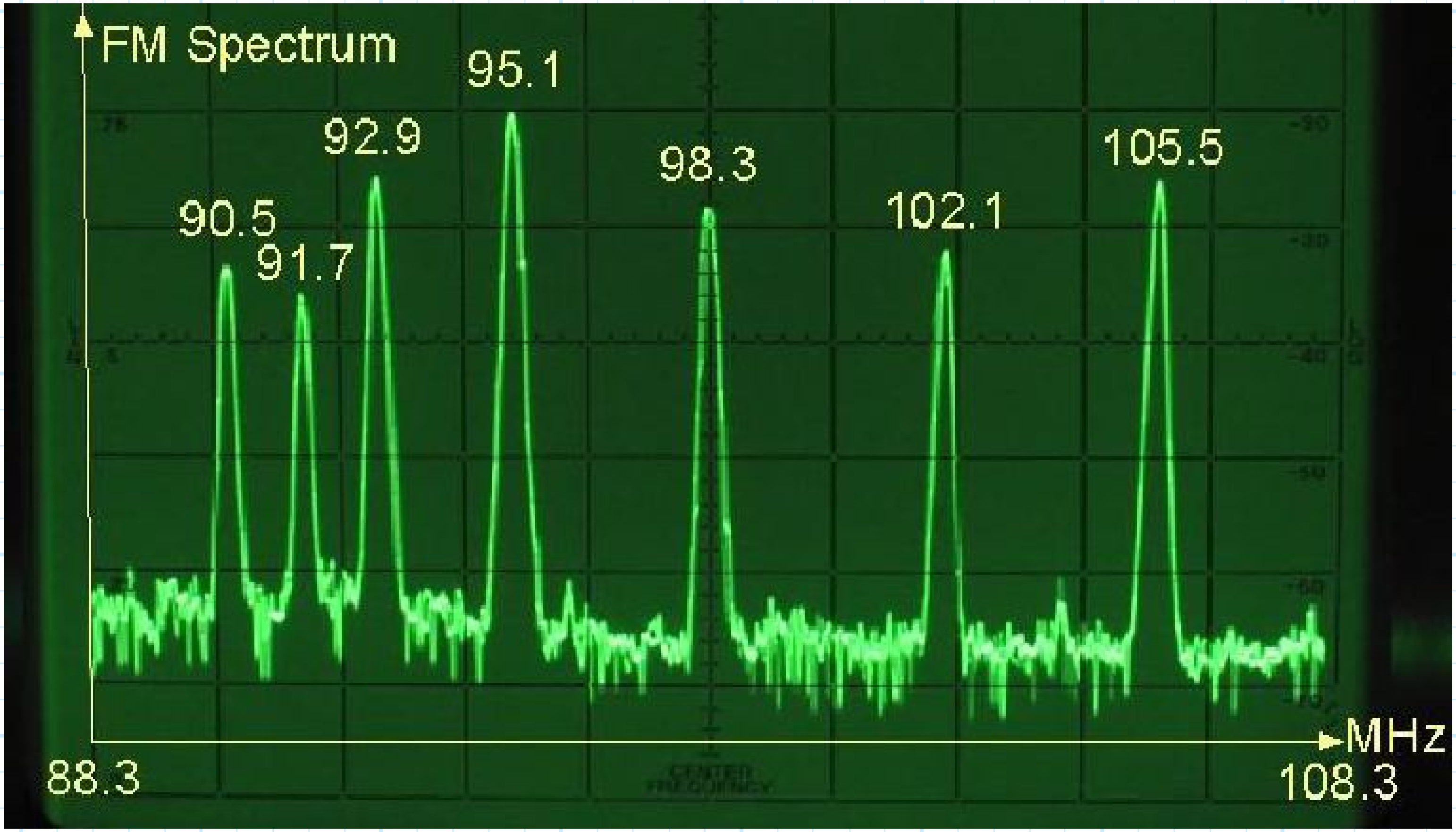
Wideband filters pass many signals

Generally speaking, we find for **wideband** filters—where **filter** bandwidth B_f is much greater than the **signal** bandwidth (i.e., $B_f \gg B_s$)—the criteria $B_s \, \Delta\tau \ll 1$ is **easily** satisfied.



In other words, signal dispersion is **not** typically a problem for wide band filters (e.g., **preselector** filters).

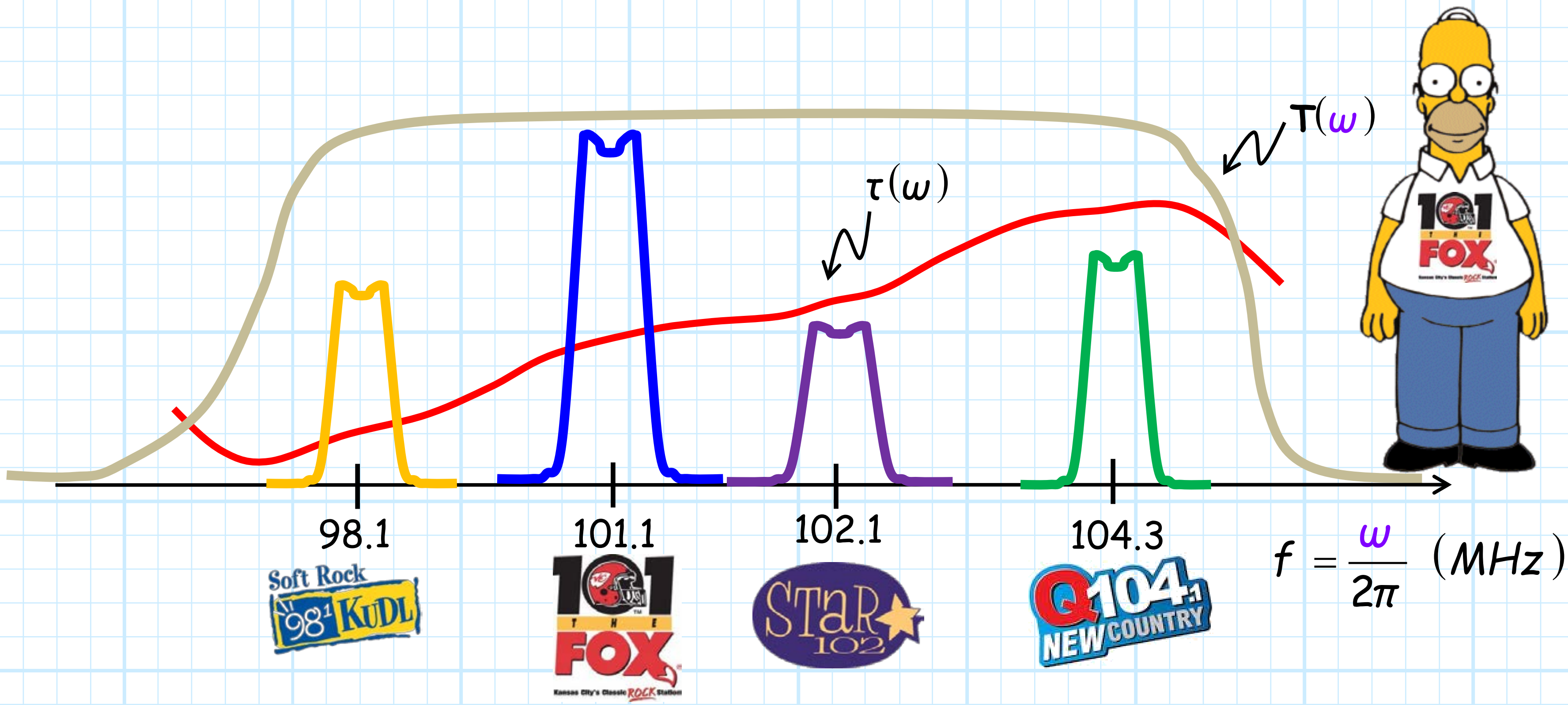
The FM radio spectrum in Saskatoon



http://een.iust.ac.ir/profs/Abolhassani/Virtual%20Lab/am_fm_pm/am-fm-rf/FM-spectrumPOP.htm

Wideband filters typically don't distort

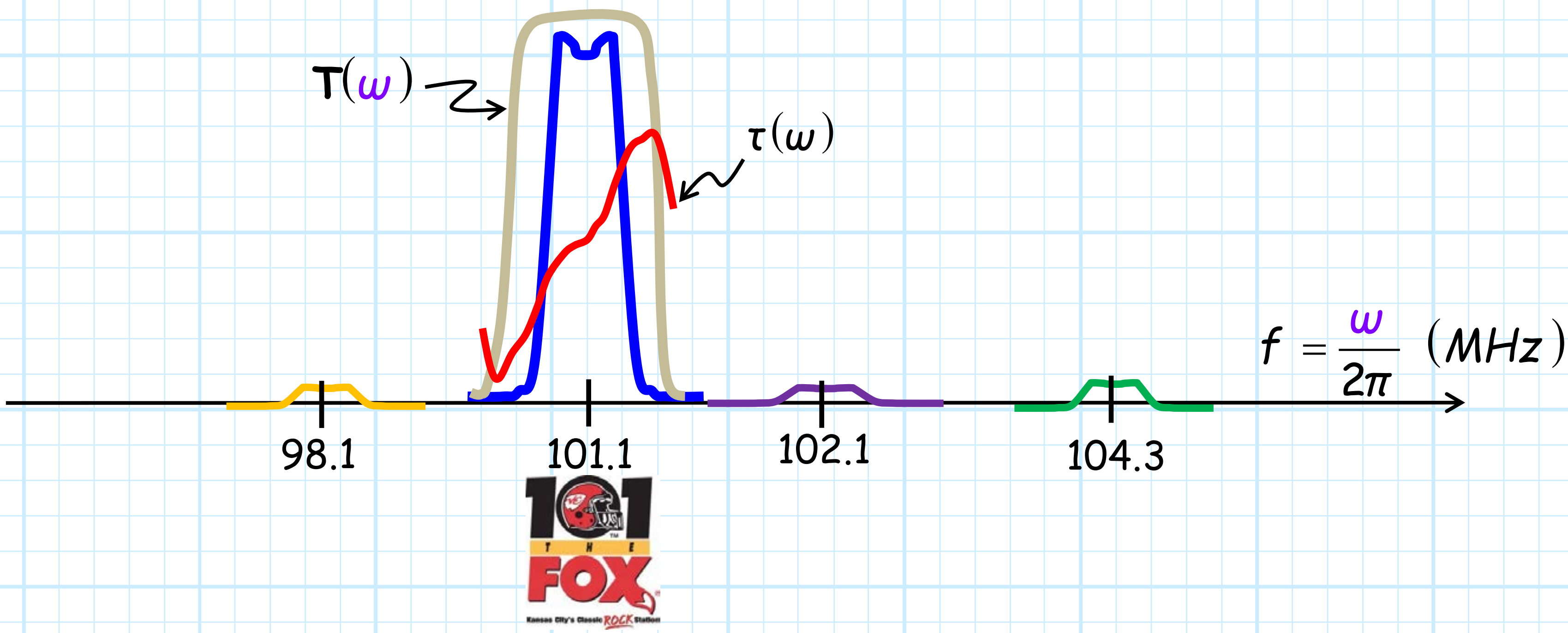
This is **not** to say that $\tau(\omega)$ is a constant for wide band filters—the phase delay can change **significantly** across the wide **filter** bandwidth:



Typically however, the function $\tau(\omega)$ does not change very **rapidly** across the wide **filter** bandwidth, so that the phase delay is **approximately** constant across the **relatively** narrow **signal** bandwidth.

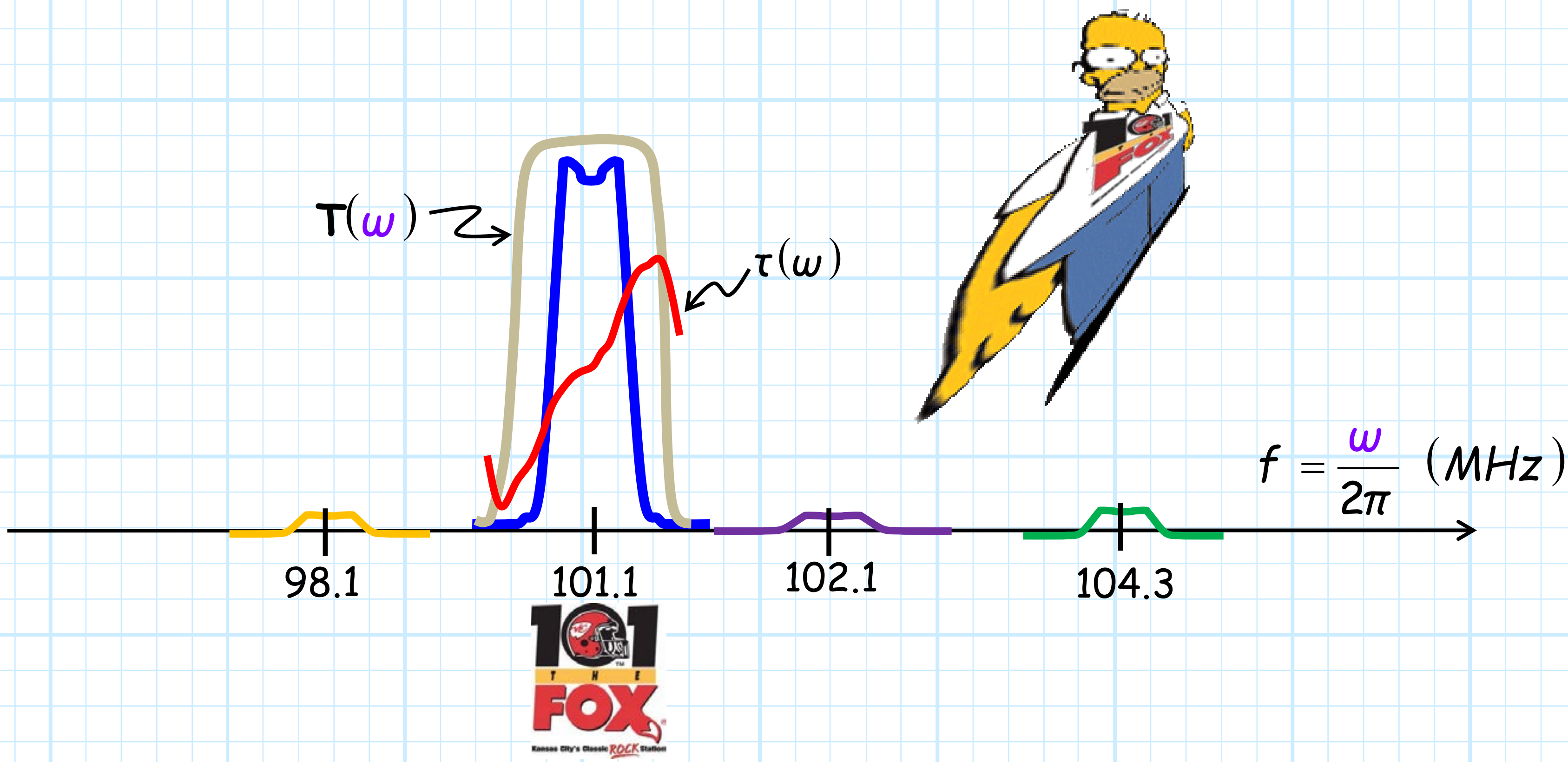
Narrow-band filters are just wide enough to pass *one* signal

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



It's those darn narrow-band filters that we need to worry about!

But, this means of course that **phase delay also** changes significantly over the **signal** bandwidth B_s!



And, this **dispersion** across the **signal** bandwidth creates **linear distortion**!

Choose the correct filter for this situation!

Thus, a **narrowband** filter (e.g., an IF filter) **MUST** exhibit a **near constant** phase delay $\tau(\omega)$—**if** it is to avoid **distortion** due to signal **dispersion**!