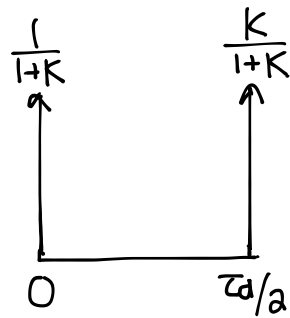


# Many Input Shapers are known in closed form:

## Zero-Vibration Shaper

- only positive impulses
- designed for 0 vibration at  $\omega_n$  and  $\xi$



$$ZV \equiv \begin{bmatrix} A_i \\ t_i \end{bmatrix} = \begin{bmatrix} \frac{1}{1+K} & \frac{K}{1+K} \\ 0 & \frac{\tau_d}{2} \end{bmatrix} \quad K = e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}}$$

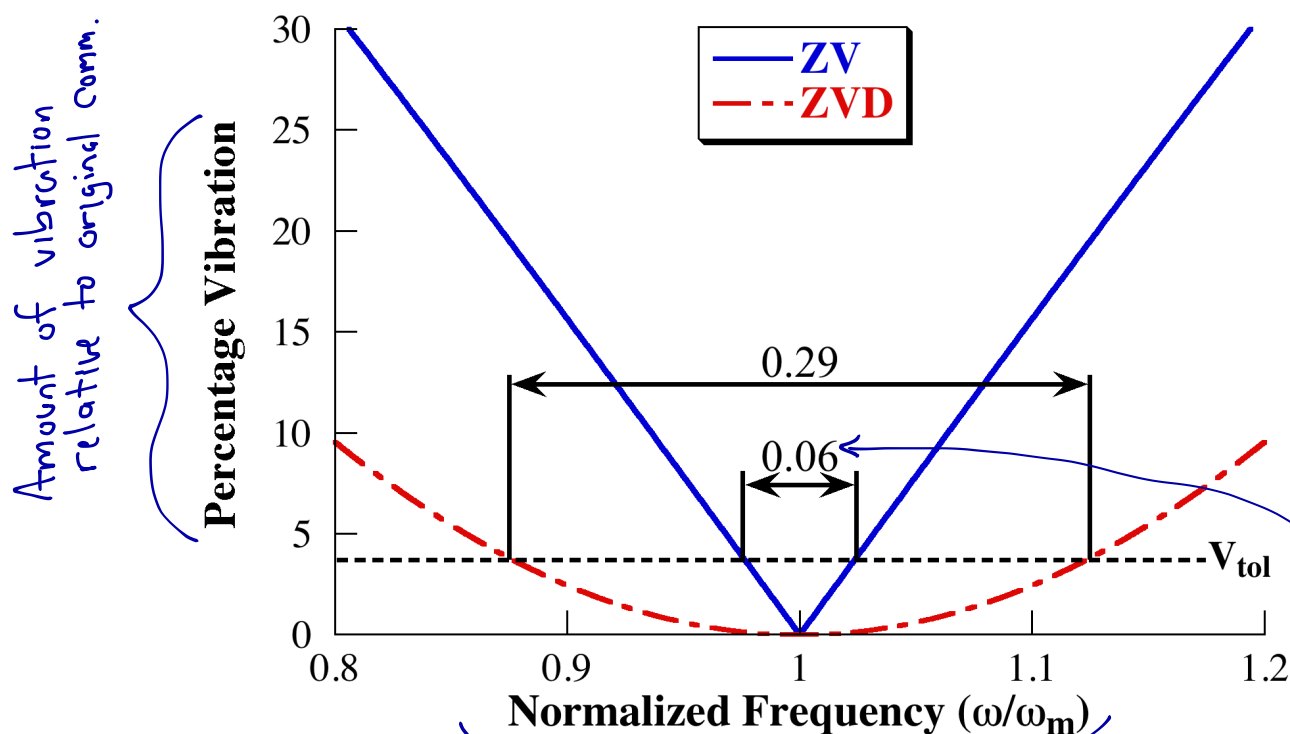
## Zero-Vibration and Derivative (ZVD) Shaper

- only positive impulses
- Zero vibration with robustness at  $\omega_n$  and  $\xi$

$$ZVD \equiv \begin{bmatrix} A_i \\ t_i \end{bmatrix} = \begin{bmatrix} \frac{1}{1+2K+K^2} & \frac{2K}{1+2K+K^2} & \frac{K^2}{1+2K+K^2} \\ 0 & \frac{\tau_d}{2} & \tau_d \end{bmatrix} \quad K = e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}}$$

## Shaper Robustness

Q: What happens if  $\omega_n$  (and/or  $\xi$ ) don't match our expected values?



Amount of vibration relative to original comm.

This is a sensitivity curve

The width of this curve below the tolerance level of vibration  $V_{tol}$  is the Insensitivity

The insensitivity of a ZV shaper at  $V_{tol} = 5\% \cdot 15$  is 0.06.

Deviation of freq. from our expectation ( $\omega_m = \text{modelled freq.}$ )

# Negative Input Shapers

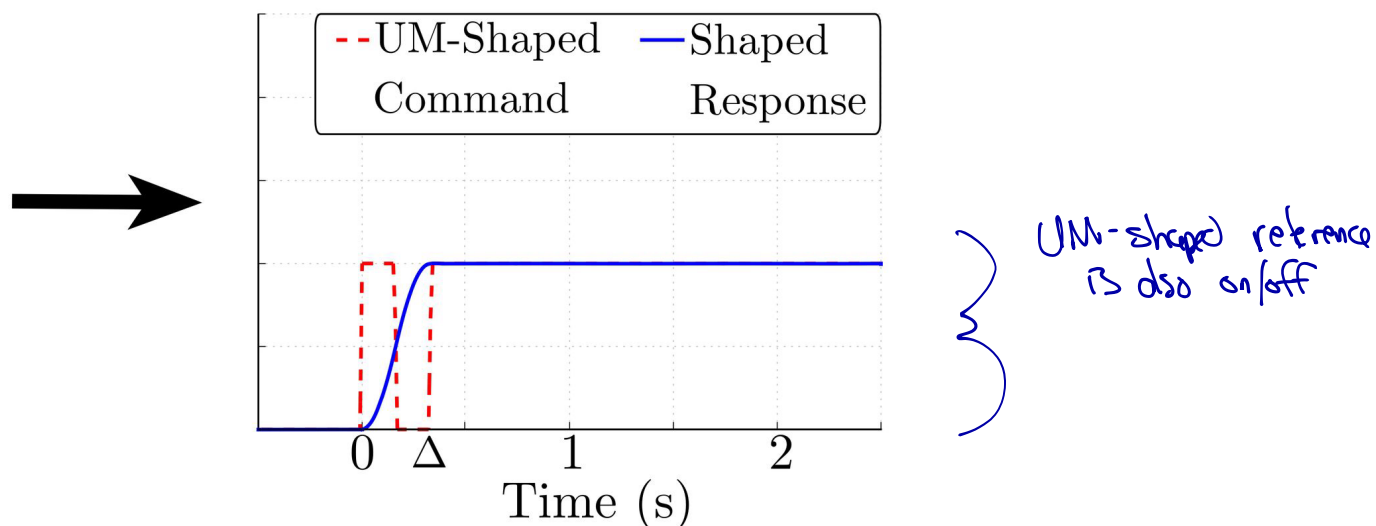
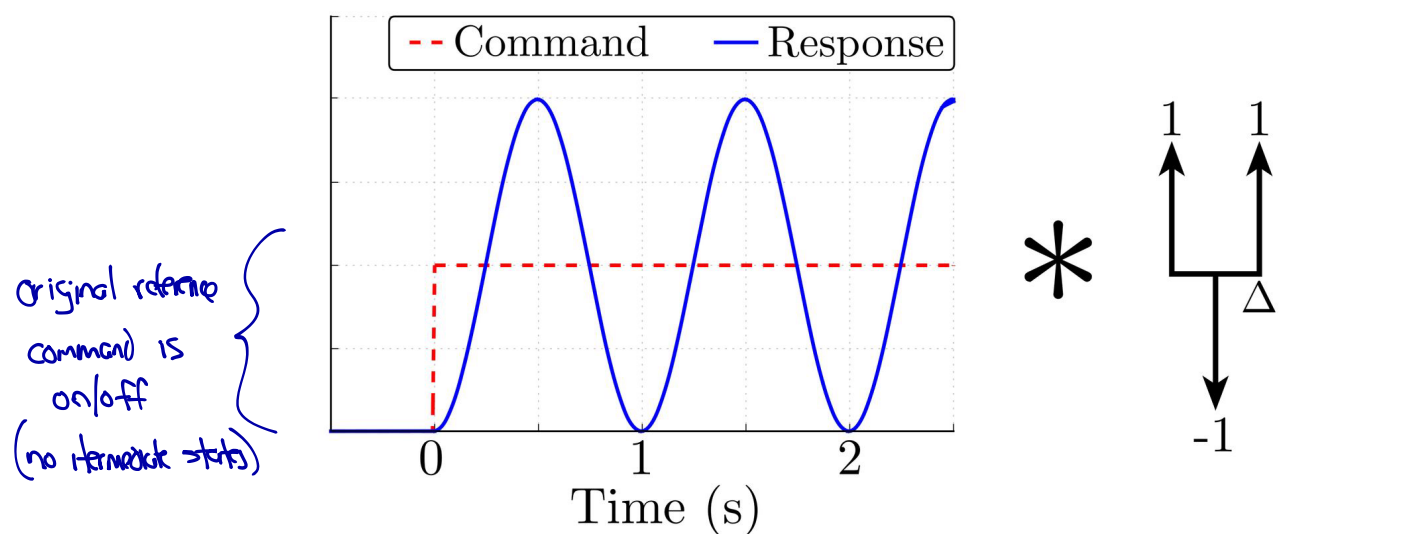
We can also allow negative impulses

## Unity-Magnitude Input Shapers

Impulses are constrained to be  $\pm 1$  (unity magnitude)

Q: What are the advantages of this over only positive impulses?

- faster
- can be used for on/off actuators  $\leftarrow$  rockets, relays, etc.



U

Q: What are potential problems with this?

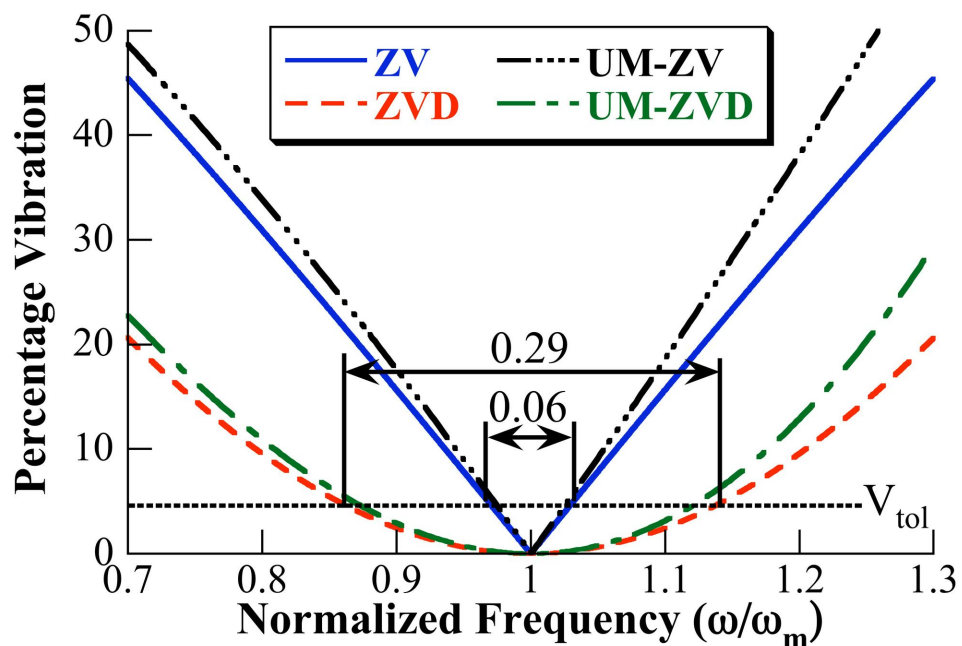
- tougher to achieve (on-off-on switching can happen too fast)
- may be "harder" on system
- high-mode excitation

Unity-Magnitude Zero Vibration (UM-ZV) shaper for undamped systems

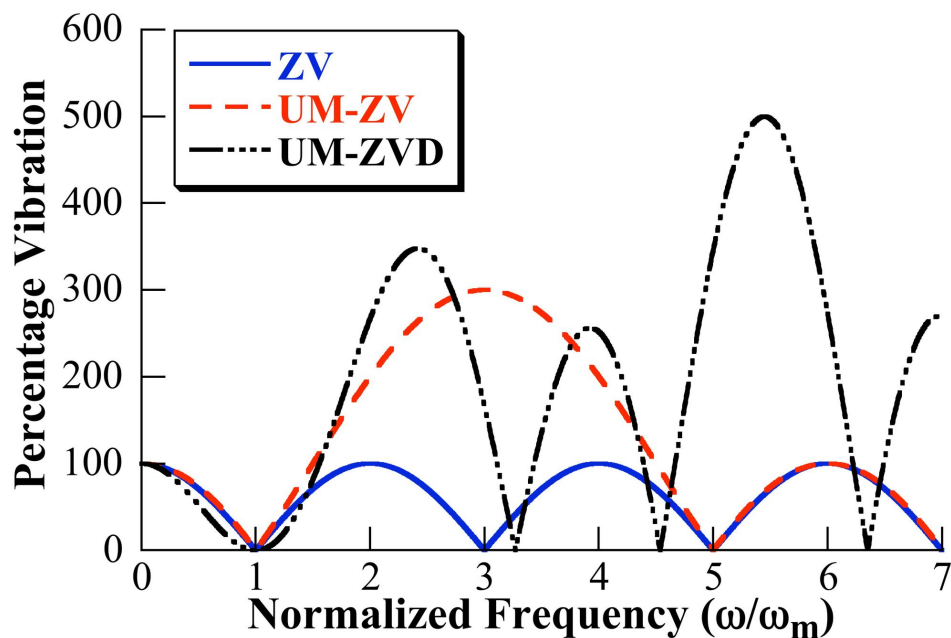
$$\text{UM-ZV} = \begin{bmatrix} A_i \\ t_i \end{bmatrix} = \begin{bmatrix} 1 & -1 & 1 \\ 0 & \frac{\tau}{6} & \frac{\tau}{3} \end{bmatrix}$$

# Robustness of Negative Shapers

Nearly identical to positive shapers near the design freq.



But, can lead to increased high-mode excitation



At frequencies much above the design freq. vibration greater than unshaped command can be excited.

Q: Why?

All UM impulses timed exactly wrong... the vibration from all impulses adds

