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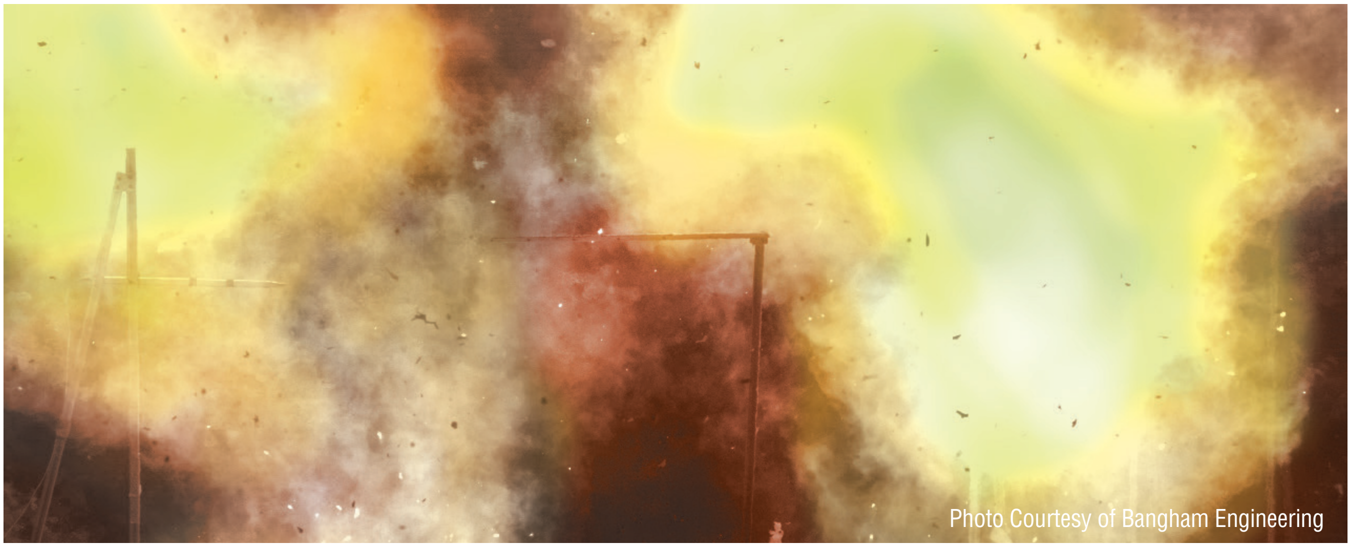

Blast Testing with the Hydrogen Unconfined Test Apparatus (HUCTA) in Huntsville, Alabama

## TN-11

# Shock and Blast Measurement-Rise Time Capability of Measurement Systems?

Written By
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# Shock and Blast Measurement - Rise Time Capability of Measurement Systems?

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Shock and blast loading of structures is characterized by a very rapid deposition of energy. When acquiring acceleration or pressure measurements from transducers mounted on test structures, it is often desired to quantify the rate (rise time) of this loading, the relative timing between loading and/or structural response events, or both. Regardless of which, it is important that we select transducers with adequate rise times to acquire these measurements with fidelity. Once this selection is complete, it is necessary to select measurement system components (amplifiers, filters, displays, etc ...) capable of maintaining this fidelity. However, measurement system components are typically specified in terms of the upper frequency at which they provide -3dB signal attenuation. A challenge then exists to infer the rise time capability of an entire measurement system based on the -3dB specifications of its individual components.

In 1948, Robert Walker and Henry Wallman, in chapter 2 of Vacuum Tube Amplifiers, McGraw Hill, 4th edition, worried about this same type problem when considering the rise time capability of vacuum tube pulse amplifiers. At that time, these amplifiers were being used in radar, television receivers, and communications equipment. Based on mathematics (central limit theorem), Walker and Wallman came up with the following rule. "For an amplifier made up of n stages, each of which is free from overshoot, rise times add as the sum of the square root." That is:

$$\tau = (\tau_1^2 + \tau_2^2 + ... + \tau_n^2)^{1/2}$$

where $\tau$ is the overall rise time and the subscripted $\tau$s are the rise times of the individual stages. For our application, the individual stages can be considered to be the various measurement system components. By combining the rise times of each of its components, we can then perform the overall assessment of the rise time capability of a given measurement system.

Fortunately, Mr. Walker and Mr. Wallman provided us with another rule: If $\tau$ is the rise time, 10 to 90 percent, of the step-function response of a low-pass amplifier without excessive overshoot and having a -3dB bandwidth $f_{-3dB}$, then:

$$\tau f_{-3dB} = 0.35 \text{ to } 0.45$$

This rule is very useful. It provides a relationship between measurement system component rise time and high frequency -3dB location. The form of this rule is somewhat of a surprise! The lower limit $\tau f_{-3dB} = 0.35$ can be derived exactly from the mathematics associated with a low-pass first order filter with a time constant of $1/(2\pi f_{-3dB})$. Such a system has a high frequency roll-off of 6dB/octave, i.e., the slowest possible. However, the surprise is that no matter how steep the roll-off of a measurement system, its shortest rise time is limited to be between $0.35/f_{-3dB}$ and $0.45/f_{-3dB}$.

To witness this rule, I ran a number of tests where the step response of various low-pass Butterworth and Bessel filters were measured. These filters had -3dB frequencies between 1,500 and 15,000 Hz and roll-offs of 24dB/octave (4th order filters). In all instances the $\tau f_{-3dB}$ product varied between 0.35 and 0.39. This variation was consistent with experimental error. To further investigate this rule, I calculated the impulse response of an ideal boxcar filter. While such a filter is not physically realizable because its step response would have to start before time = 0, its rise time and -3dB relationship were shown to be $\tau f_{-3dB} = 0.44$. This value correlates very well with the 0.45 value postulated in 1948.

Before providing some application examples, one final rule will be provided. Many transducers behave as resonant systems. If the rise time they encounter in service is too short, their resonant frequency is excited and superposed on the recorded data. To preclude significant resultant overshoot from occurring, a rule of thumb for these type transducers is:

$$\tau f_n \geq 2.5$$

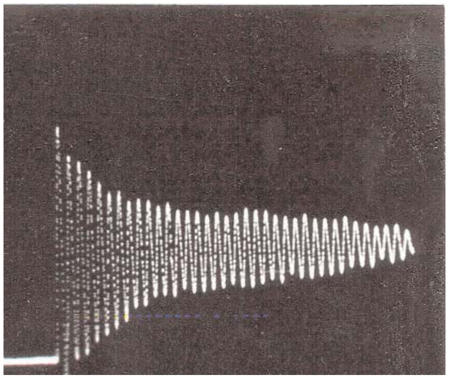
where $\tau$ is the 10-90 percent rise time as before and $f_n$ is the resonant frequency of the transducer.

The following figures provide the response of two types of pressure transducers to submicrosecond rise time pressures. The first transducer behaves as a resonant system and the second transducer pair as a nonresonant system (PCB Model 134A pressure bar).

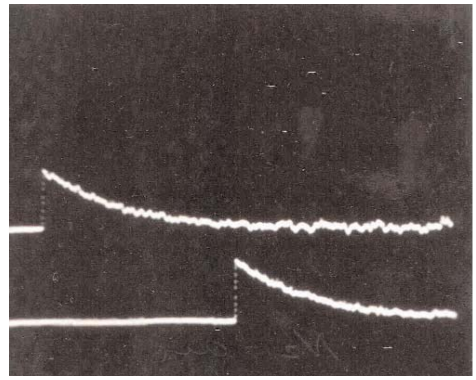
Now that the requisite "rules of thumb" have been provided, two application examples of them are presented.

Example 1:

A nonresonant pressure transducer has a 1 microsecond ($\mu s$) rise time. Its signal passes through an amplifier with a -3dB frequency of 250 kHz. The signal is filtered before digitization by a filter with a -3dB frequency of 100 kHz. After digitization, the signal is displayed on a recorder with a 1 MHz capability. Is the system capable of measuring pressure rise times of 3 $\mu s$?



**Resonant transducer response to submicrosecond step input**



**Nonresonant transducer pair response to submicrosecond rise time inputs**

Determination:

| | |
|---|---|
| Transducer rise time (given): | 1 $\mu s$ |
| Amplifier rise time:<br>($\tau f_{-3dB}$ = 0.45 for most conservative value) | 1.8 $\mu s$ |
| Filter rise time:<br>($\tau f_{-3dB}$ = 0.45 for most conservative value) | 4.5 $\mu s$ |
| Recorder rise time:<br>($\tau f_{-3dB}$ = 0.45 for most conservative value) | 0.45 $\mu s$ |
| System rise time:<br>(square root of the sum of the squares) | 4.97 $\mu s$ |

Answer: No. The measurement system rise time is 4.97 $\mu s$, which is longer than the 3 $\mu s$ rise time it is desired to measure.

Example 2:

A piezoelectric accelerometer has a fundamental resonant frequency of 50 kHz. It is desired to record a shock pulse with a rise time that may be as short as 50 $\mu s$. A charge amplifier is available with a -3dB frequency of 100 kHz. A digital recorder has an associated - 3dB frequency of 1 MHz. Are these measurement system components adequate for their intended use?

Determination:

| | |
|---|---|
| Transducer rise time:<br>($\tau f_n$ = 2.5 to determine shortest) | 50 $\mu s$ |
| Amplifier rise time:<br>($\tau f_{-3dB}$ = 0.45 for most conservative value) | 4.5 $\mu s$ |
| Recorder rise time:<br>($\tau f_{-3dB}$ = 0.45 for most conservative value) | 0.45 $\mu s$ |
| System rise time:<br>(square root of the sum of the squares) | 50.2 $\mu s$ |

Answer: No. The measurement system rise time is 50.2 $\mu s$, which does not provide design margin relative to the 50 $\mu s$ it is desired to measure. The observed rise time should be approximately 5-times the system rise time to be unaffected. Therefore, it would be preferable to acquire an accelerometer with a fundamental resonance above 250 kHz.

Hopefully, these two examples have helped to illustrate how to apply these "rules of thumb" to assess the capability of measurement system components, and thus the overall measurement system, in order to acquire fast rise time data.

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