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Introduction to Air Blast Measurements - Part IV

Getting the Signal Down the Cable

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Introduction to Air Blast Measurements - Part IV: Getting the Signal Down the Cable

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In Parts I, II and III of this series, we provided an understanding of the air blast environment and the operation of transducers intended to measure it. We went on to describe how to mount these transducers to optimize their dynamic response and how to validate the resultant signal output from the transducers. These considerations alone don't guarantee success unless we are able to transmit the signal down the cable with fidelity. Since, as mentioned previously, 100's or 1000's of feet of cable can be involved, signal distortion can occur.

For the following discussion, the consideration of a lossless transmission line (one whose resistance is ignored) will suffice. A voltage signal v going down the line is a function of both space (z) and time (t), i.e., $v = v(z,t)$. Its equation can be given as[6]:

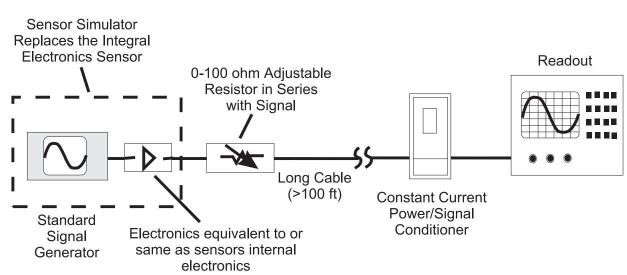
$$\partial^2 v(z,t)/\partial z^2 = lc\left[\partial^2 v(z,t)/\partial t^2\right] \tag{4}$$

where l and c are the line inductance and capacitance per unit length. This is the classical wave equation that governs many other physical phenomena such as stress wave transmission in a bar and acoustic wave transmission in an organ pipe. By analogy, $1/\sqrt{lc}$ has a dimension of velocity.

Many facilities where air-blast testing is performed also measure and record data from strain gages and other bridge type circuits. Therefore, 4-wire shielded cable is typically used. A representative instrumentation cable could be: Belden[7] non-paired #82418, 4-conductor, 18 AWG, fluorinated ethylene propylene insulation, Beldfoid® shielded, with an inductance of 0.15 µH/foot and a conductor-to-conductor capacitance of 30 pF/foot. Using the above equation ($1/\sqrt{lc}$) to calculate the propagation velocity for this cable results in 0.47 x 10^9 ft./sec., or roughly 0.5 x the speed of light.

The characteristic impedance for a lossless line is expressed as $\sqrt{l/c}$, which for the preceding cable can be calculated to be 70.7 ohms. If the cable is terminated properly ($\sqrt{l/c}$ = 70.7 ohms), there will be no reflections at high frequencies. However, if the cable is not terminated properly (e.g., if it operates directly into a high impedance amplifier (typically

A typical blast sensor installation requires long cables for signal transmission. Data acquisition equipment may be thousands of feet away.



Block diagram of a system that tests and tunes long cables for optimal performance.

R≥1MΩ), reflections can occur. The first reflection will occur at a frequency (f) corresponding to a wavelength (λ) equal to four (4) times the cable length.

As an example, arbitrarily pick the highest signal frequency of interest to be 100,000 Hz. The corresponding wavelength is:

$$\lambda f = (4L)f = \text{propagation velocity or}$$

$$\lambda = 4L = (0.47 \times 10^9 \text{ ft./sec.})/(1 \times 10^5 \text{ Hz.}) = 4700 \text{ ft.} \tag{5}$$

Thus, a cable length of (4700/4) or 1175 feet will result in oscillations at a frequency of 100,000 Hz. In addition, signal fidelity can only be maintained to approximately 20,000 Hz, which is one-fifth the frequency of oscillation.

Figure 12 shows an obtained, experimental frequency response for 400 feet of a 4-conductor shielded Belden instrumentation cable of #22 AWG. Note the resonant frequency at 330,000 Hz for the infinite load (R = 1MΩ). If we calculate the fundamental wavelength for this cable, and again use 0.47 x 10^9 ft./sec., which is an approximation for this cable, we get λ = 4L = (0.47 x 10^9 ft./sec.)/(3.3 x 10^5 Hz.) = 1,424 ft. or a cable length of 1,424/4 = 356 feet, which agrees reasonably well with the known value of 400 feet. Thus, when high frequencies and long cable runs are involved, cable termination and impedance matching are very important. Note the improvement in constant or "flat" frequency response with the R = 100Ω termination.

There is only one opportunity to acquire data during a blast test. Ensuring the validity of acquired data is essential.

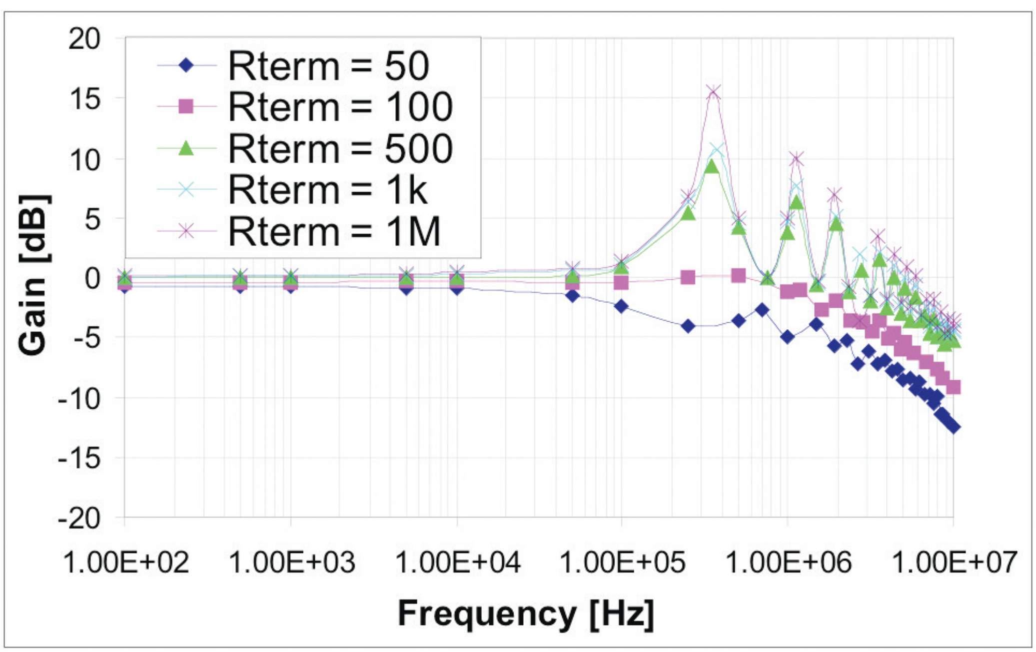
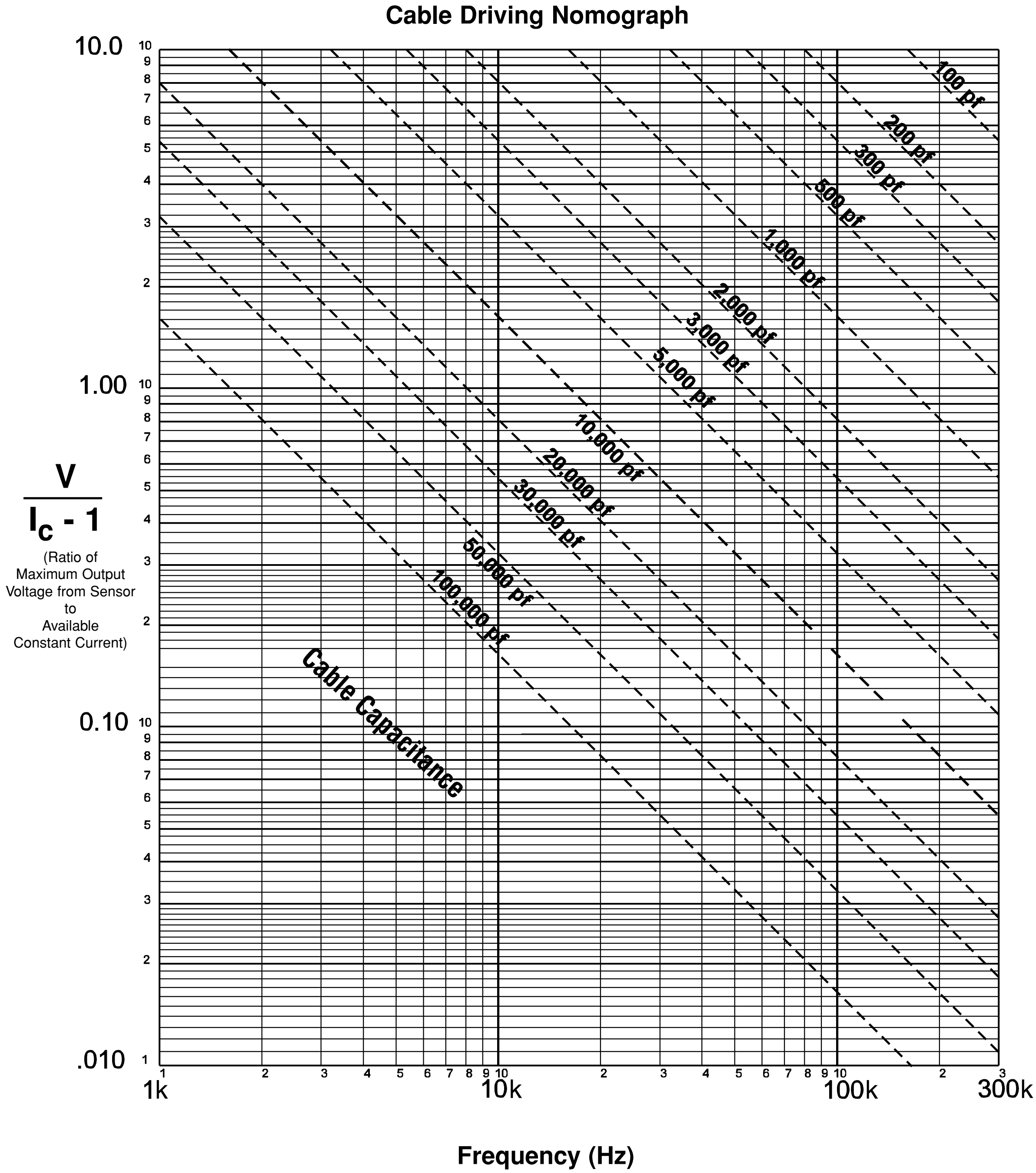


Figure 12:
Response of Belden 22 AWG 4-Conductor Cable
as a Function of Termination



f_{max} = Maximum frequency given the following characteristics

C= Cable capacitance (pF)
V= Maximum output voltage from sensor (volts)
I_c= Constant current level from power unit (mA)
10^9= Scale factor to equate units

Figure 13:
Nomograph Showing Effect of Frequency and Cable Capacitance
On ICP® Signal Output

IEPE or ICP® sensors have an additional limitation associated with their high frequency response. For very long cable runs, one has to assure that there is adequate current to drive the cable capacitance. If the time varying current $i(t)$ supplied to the cable is $i(t) = (\mathrm{I})\sin(2\pi ft)$, then at low frequencies:

$$v(t) = (1/C)\int i(t)dt = [(\mathrm{I}/2\pi fC)\cos(2\pi ft)] \tag{6}$$

Here, C is the total cable capacitance. It can be seen that the magnitude of the measured voltage is inversely proportional to C, which is itself proportional to the length of the cable, so the measured voltage goes down with increasing cable length. The same inverse relationship holds for frequency. Conversely, the voltage is directly proportional to the current.

The nomograph in Figure 13 plots these relationships. To use this nomograph, let's take the previous example of the Belden #82418 cable with capacitance of 30 pf/foot. If we encountered 1,000 feet of cable (which is a moderate amount for air-blast testing) back to a recording station, total capacitance would be 30,000 pF. If 100,000 Hz response and a maximum of 1 volt of signal level are required, the nomograph provides a value of $V/(i_c\text{-}1)$ of 0.055. Note i_c is in mamp and 1 is subtracted to account for the current required to power the ICP® sensors electronics. Substituting, $1/(i_c\text{-}1) = 0.055$ would result in a required supply current of 19.2 milliamps. 20 mamps tends to be the maximum supply current for ICP® circuits. If 5 volts maximum signal were required, and the maximum supply current were provided, $V/(i_c\text{-}1) = 5/(20\text{-}1) = 0.263$. Entering the table where 0.263 on the ordinate intersects 30,000 pF yields an upper frequency limit of about 21,000 Hz. While proper cable termination (impedance matching) is likely not required for the 21,000 Hz signal, it definitely would be for the 100,000 Hz signal.

In some instances lower-capacitance cables can be substituted. For example, RG-62 type cable has one-half the capacitance-per-foot as does RG-58 type cable. However, it should always be remembered that when long cable lengths and high frequencies are involved, attention should be directed to both the inductance and capacitance of the cable. When possible, the cable frequency response should be checked by driving it through the same type ICP® circuit as will be used in application.

6. Matick, Richard L., Transmission Lines for Digital and Communication Networks, IEEE Press, pp.31-35, 1995.

7. Belden CDT Inc., St. Louis, Missouri

Please refer to PCB Tech Notes 12, 13 *and* 18 *for full text of* Parts I, II *and* III *of the* "Introduction to Air Blast Measurements" *Series*

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