Condition Monitoring

PRÜFTECHNIK AG

TechNote #18 Line Drivers

The benefits of line drivers for remote sensing

Introduction

If you are setting up a machine monitoring network in a large plant such as a paper mill then the cables from the sensors to the central computer are going to be rather long, perhaps over 100m (~330'). These vulnerable cables will probably have to stand up to considerable electrical and mechanical interference along the way, and with traditional sensors the signals barely get through, being drowned out by the noise.

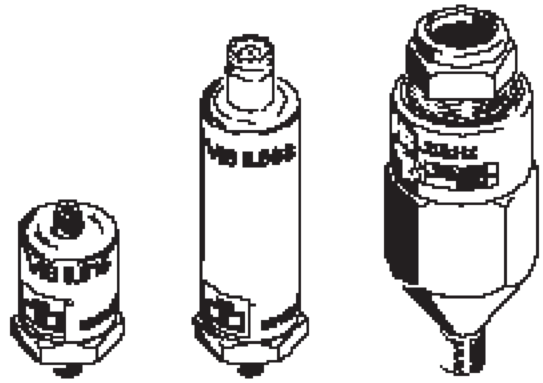
You have a choice: use either expensive high-quality cable carefully laid away from interference sources, or use a 'line drive' system. A line drive* system consists of a tiny electronic amplifier built into each sensor which boosts the vibration signal. This gives the following advantages:

- Low sensitivity to mechanical and electrical interference (cable noise, electromagnetic sources, ground looping)
- Very long low-cost cables possible with very little signal loss
- Cable positioning during installation is not as critical
- Power supply current carried along the very same coaxial cable carrying the vibration signal (power comes from a source built into the receiver instrument)

The circuitry in the accelerometer weighs only a couple of grams and has negligible effect on the dynamic range or influence when measuring very light or small structures. Note though that the electronics restrict the operating temperature range of the accelerometer (up to 125°C, 257°F).

Line drivers are only recently becoming popular in the field of remote monitoring but have been used as standard for two decades by stage musicians requiring noise-free signals through moving cables in an environment fraught with electrical interference.

PRÜFTECHNIK accelerometers with built-in line drive amplifiers



Compact accelerometer VIB 8.515 | Accelerometer VIB 8.508 | Industrial accelerometer VIB 8.513

PRÜFTECHNIK line drive systems

The choice is quite simple with PRÜFTECHNIK. Most of our accelerometers contain built-in line drive amplifiers and our vibration measurement systems all feature the required built-in line drive power supply: VIBROSPECT® FFT, VIBROTIP® and most recently, VIBRONET®.

The following pages describe in detail the influences cables have on a vibration signal and how line drivers minimize these effects. There are also comparisons between the PRÜFTECHNIK system and competitor systems currently on the market.

*The term 'line drive amplifier' was originally used by Brüel & Kjaer (Naerum, Denmark) for this type of circuit. We use the same term for sake of familiarity although there are technical differences between the B&K system and the PRÜFTECHNIK system.

Signal loss and noise in cables

The cable is an important part of the overall system and affects the signal in several ways:

Signal loss effects

- High temperatures cause gradual cable breakdown and leakage at low frequencies.
- Long cables can cause high frequency loss.

Mechanical noise

Cable motion generates an electrical charge which results in cable noise. This is called the triboelectric effect and can be minimized by using low noise cable and clamping it down.

Electromagnetic noise

This has several sources:

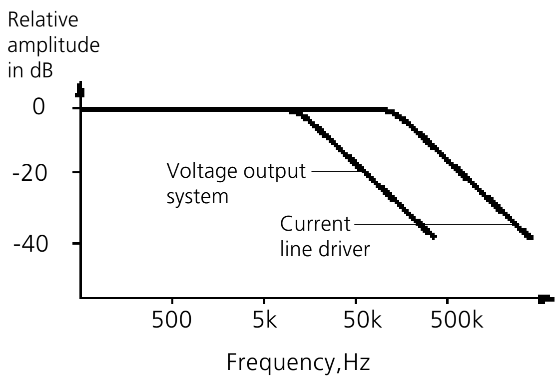
- Power cables nearby exerting an inductive influence on the signal cable
- Spikes from ignition or high current high speed switching systems
- RF pickup from radio equipment
- Ground loops cause mains hum when the machines are not properly earthed.

The advantages of PRÜFTECHNIK current line drivers

There are two types of line drive systems on the market, with either a voltage output or a current output. PRÜFTECHNIK systems have a current output. This is a superior system with more sophisticated electronics and the following significant advantages:

- Much lower high frequency loss in very long cables even over 1km.
- Much lower susceptibility to induced noise and ground-loop noise, also obviating in most cases the need for insulated sensors.

Frequency loss in 100m / 325 ft. coaxial cable



High frequency loss in long cables

The PRÜFTECHNIK current line driver system has much lower high frequency loss in long cables than voltage output systems.

This is because the instrument has a significantly lower input impedance, and since the maximum frequency is inversely proportional to input impedance, the maximum frequency is greatly extended.

A technical comparison between the PRÜFTECHNIK system and competitor systems is given on the opposite page.

Ground looping and noise

The PRÜFTECHNIK current line driver system has much lower susceptibility to induced noise and ground-loop noise than voltage output systems.

This is because the very low instrument input impedance minimizes influence from electro-magnetic fields. The instrument virtually 'shorts' the cable conductors.

This has the added advantage that costly insulated sensors can usually be avoid, also elliminating the problem of insulator capacitance.

Technical details are given on the back page.

Maximum frequency for long cables

A technical comparison

Voltage output line drivers

In voltage output systems (see diagram below) the sensor generates a varying voltage, $U(t)=U_o+U_{\sim}$ where U_o is the average level and $U_{\sim}$ is proportional to the mechanical vibration. The maximum rate of change of this voltage depends on the current, I and the cable capacitance, C according to the formula

$$[dU(t)/dt]_{max} = I/C$$

For a 100m cable with capacitance of 100pF/m and a current of 2mA, then (substituting F=As/V),

$$[dU(t)/dt]_{max} = I/C = 2mA / 10nF = 0.2V/ms$$

We can calculate what sort of frequency this maximum voltage rate represents. If Û is the amplitude, then for a sine wave,

$$U(t) = \hat{U}\sin wt, \text{ and } dU(t)/dt = \hat{U}w \cos wt$$

The maximum gradient is when cos wt =1, therefore $[dU(t)/dt]_{max} = \hat{U}w = 2pf\hat{U}$

For Û=1V and $[dU(t)/dt]_{max}$ = 0.2V/ms as before,

$$f_{max} = [dU(t)/dt]_{max}/2p\hat{U} = 0.2V/ms / 2p\bullet 1V \text{ » } 30kHz$$

The maximum frequency* that can pass along a 100m cable with this system is therefore 30kHz.

For a **300m** cable this would be limited to **10kHz**.

PRÜFTECHNIK current line drivers

In the PRÜFTECHNIK arrangement the signal is gen erated in the sensor as a modulated current, I(t).

In this case the limiting frequency is independent of the voltage level and is governed principally by the RC circuit where R = input impedance, and C = cable capacitance, according to the following formula:

f_{max} =1/(2pRC)

For R = 30W (+ 0.05W/m) and C = 100pF/m then,

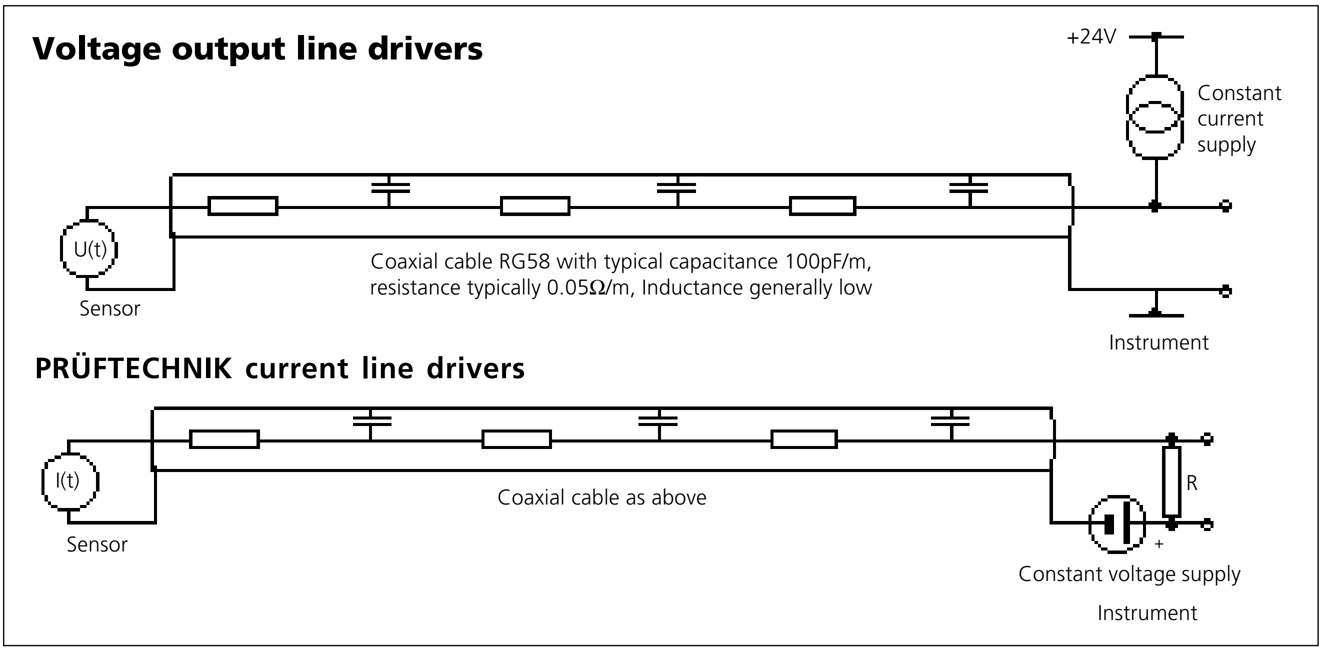
f_{max} = 1/(2p • 35W • 10^{-8}F) » 450kHz

The maximum frequency* that can pass along a 100m cable with this system is therefore 450kHz.

For a **300m** cable this would be limited to **120kHz**

Summary

- Voltage output systems significantly limit the maximum frequency in long cables (e.g. to 30kHz for 100m).
- In bearing diagnosis, frequencies well above 30kHz are present.
- **The PRÜFTECHNIK system has a good ten-fold improvement on frequency response!**

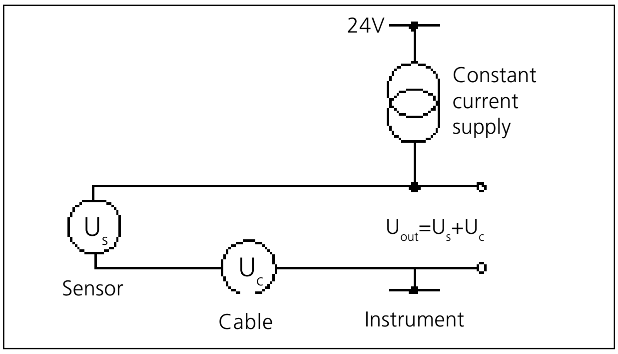


*The maximum frequencies given by these formulae are for a -3dB (~30%) loss. Above this point the response falls rapidly at 20dB per decade.

Ground looping and noise

A technical comparison

Voltage output line drivers



In voltage output systems the sensor generates a varying voltage,

$$U_s = U_o + U_{\sim}$$

where U_o is the average level and $U_{\sim}$ is proportional to the mechanical vibration.

Induced noise is generated in the cable as a varying voltage, U_c

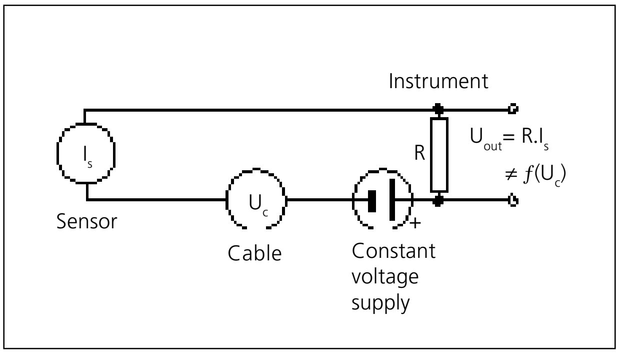
The total voltage measured at the instrument is simply the sum of these i.e.

$$U_{out} = U_s + U_c = U_o + U_{\sim} + U_c$$

in summary,

Noise combines directly with the vibration signal.

PRÜFTECHNIK current line drivers



In the PRÜFTECHNIK system the sensor generates a varying current,

$$I_s = I_o + I_{\sim}$$

where I_o is the average level and $I_{\sim}$ is proportional to the mechanical vibration.

Induced noise is generated in the cable as a varying voltage, U_c

Since the voltage in this system is constant, the induced voltage has minimal influence on the modulated current:

$U_{out} = R \bullet I_s$ ¹ ¦(U_c)

in summary,

The vibration signal is highly immune to noise!

Bibliography

For further reading on the subject of machine monitoring:

Vibration handbook, PRÜFTECHNIK AG, order no. VIB 9.433G
Offers a good general introduction to vibration measurement.

Piezoelectric Accelerometers and Vibration Amplifiers, 1987, Brüel and Kjaer, Naerum, Denmark
Compares the different amplifier systems and discusses the advantages of line drivers.

Machinery Analysis and Monitoring (Second Edition, 1993), John S. Mitchell, PennWell Books, ISBN 0-87814-401-3
An excellent general reference book on all matters pertaining to machine vibration measurement.

Shock and Vibration Handbook (Third Edition, 1988), Cyril M. Harris, McGraw Hill, ISBN 0-07-026801-0
1312 pages of in-depth detail. For the professional!

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