1.0 DYNAMIC AMPLIFIERS FOR STRAIN GAUGING

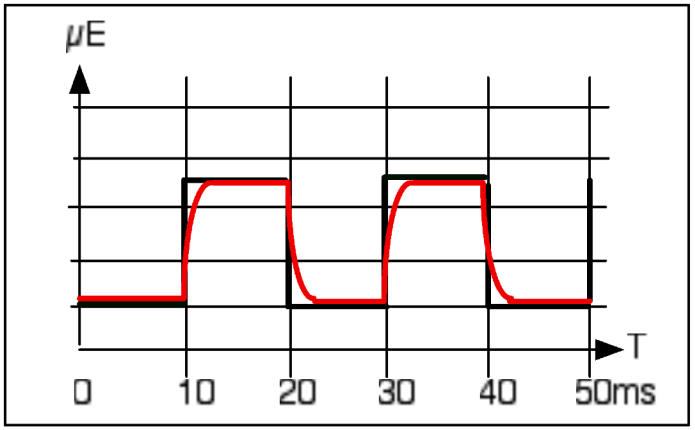
What do we mean by "Dynamic"?

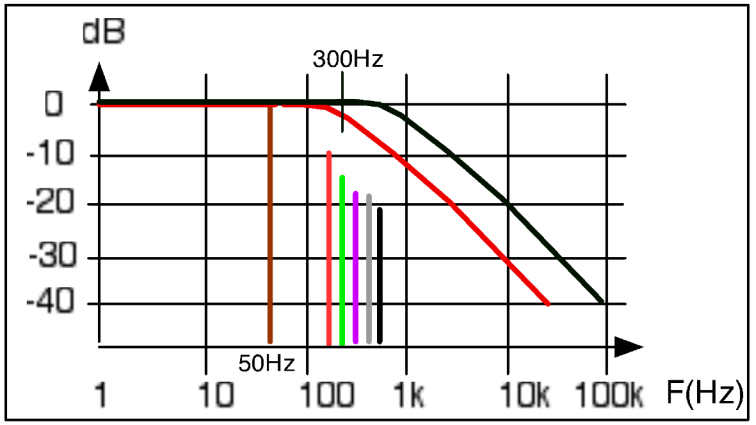
- Strains are varying with time, often at a high rate.
- They may be cyclic or transient.
- There may be a static content too - but we don't need the information in this instance.

- A 'DC' Strain Gauge Amplifier may be ok to use, but some are low frequency only. Does the bandwidth you need match the amplifier's capability?

1.1 HOW MUCH BANDWIDTH DO YOU NEED?

Make sure that you can pass the highest frequency you need to measure.
Eg: A square wave signal has odd harmonics (3rd, 5th, 7th etc).



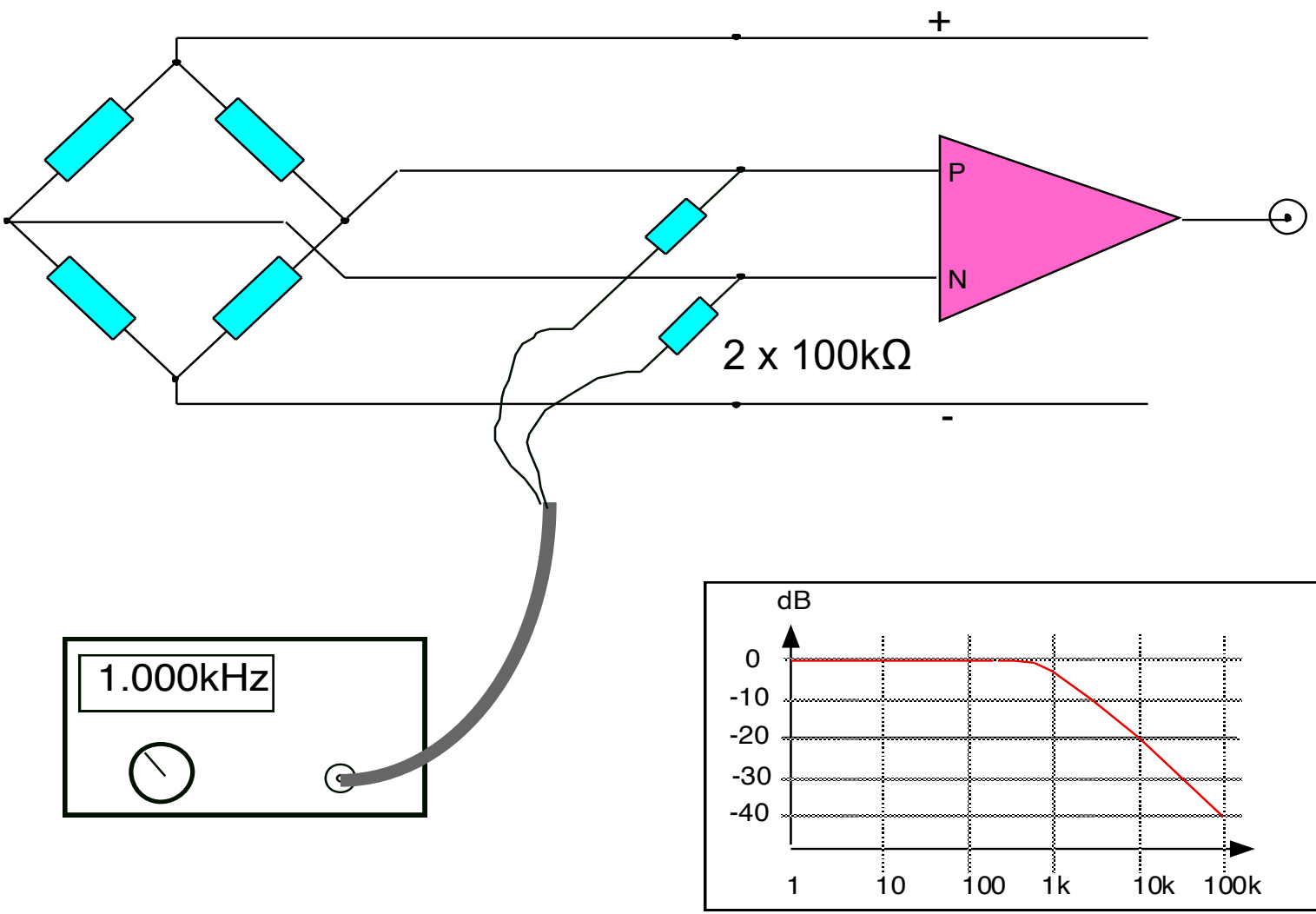


The black square wave shown left has a fundamental frequency of 50Hz.

1kHz bandwidth passes the 7th harmonic (350Hz) at just 0.5dB loss.

300Hz bandwidth severely attenuates even the 5th harmonic (250Hz) and will cause distortion as shown in red.

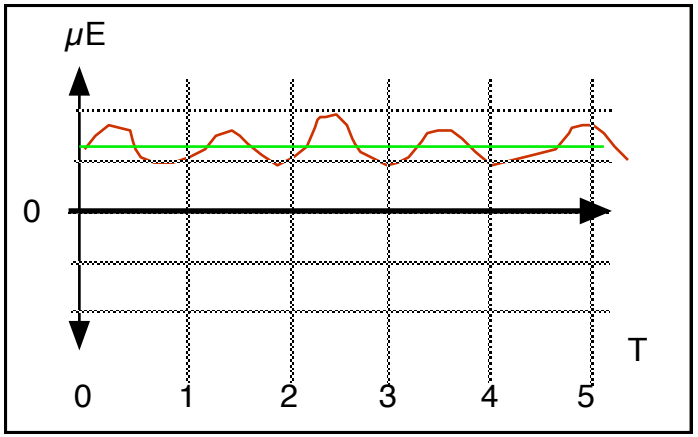
1.2 BANDWIDTH : TEST IT!

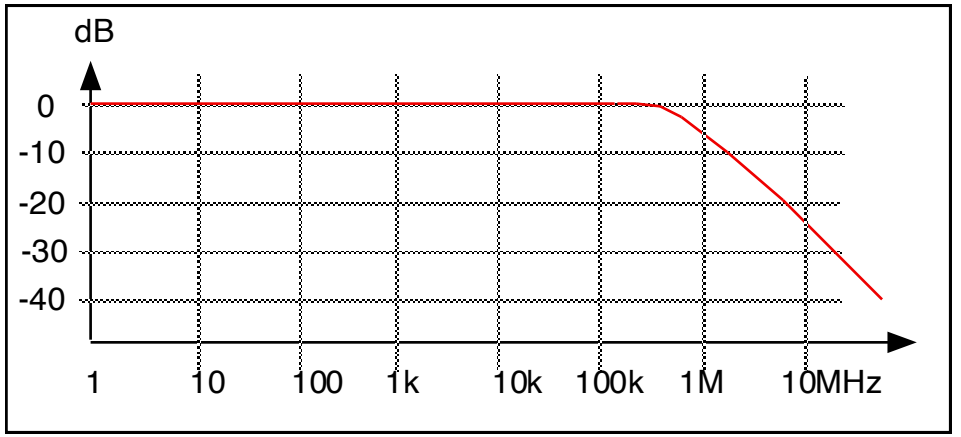


1.3 HIGH SPEED DC STRAIN GAUGE AMPLIFIER

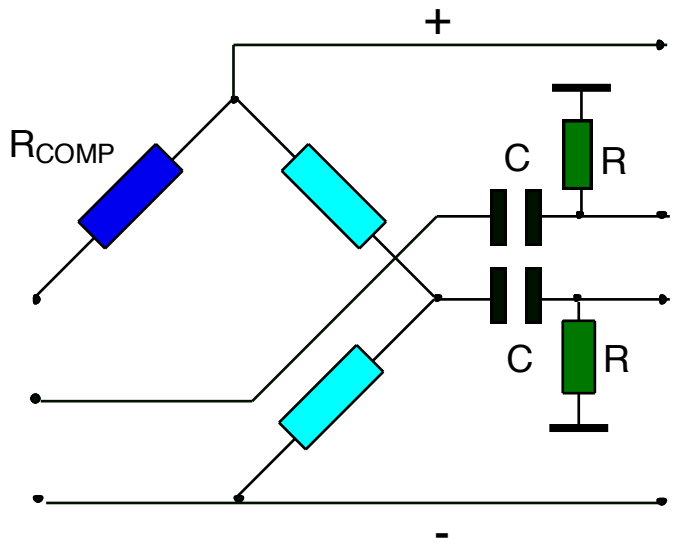
FE-H379-TA

- DC to >500kHz Bandwidth.
- Digital Auto-Zero (auto-balance).
- 30kHz, 100kHz, 300kHz, 1MHz filter settings.
- Pre-calibrated gain. Shunt cal and voltage cal.
- Completion for single and double gauges.



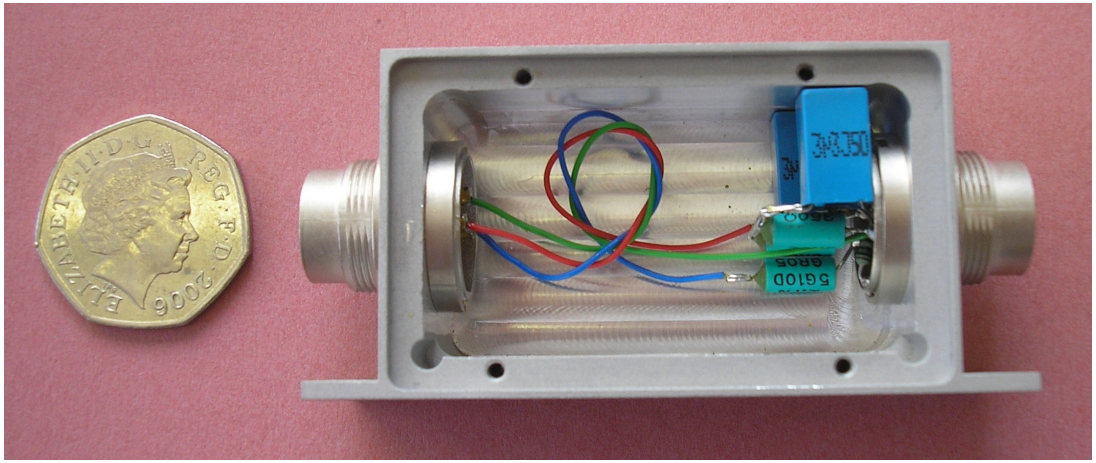


1.4 1/4 BRIDGE ‘AC’ ADAPTOR



Fc (-3dB) = 1/2πCR

(3µ3 & 33kΩ is 1.6Hz -3dB)



1.5 ’DC’ CONNECTION SUMMARY

You can make Dynamic measurements with DC coupled Strain Gauge Amplifiers subject to the following provisos…

- You will need to balance to bring the output “on scale”.
- Static Strain is also included - unless you “AC couple”.
- In harsh environments, you may have temperature drift.
- Some DC amplifiers lack bandwidth: “1kHz bandwidth” may mean **-3dB (-30%!)** at 1kHz. So check the spec, ask the manufacturer, or “Test It” if you are unsure.

2.0 ’AC’ CONNECTION DISCUSSION

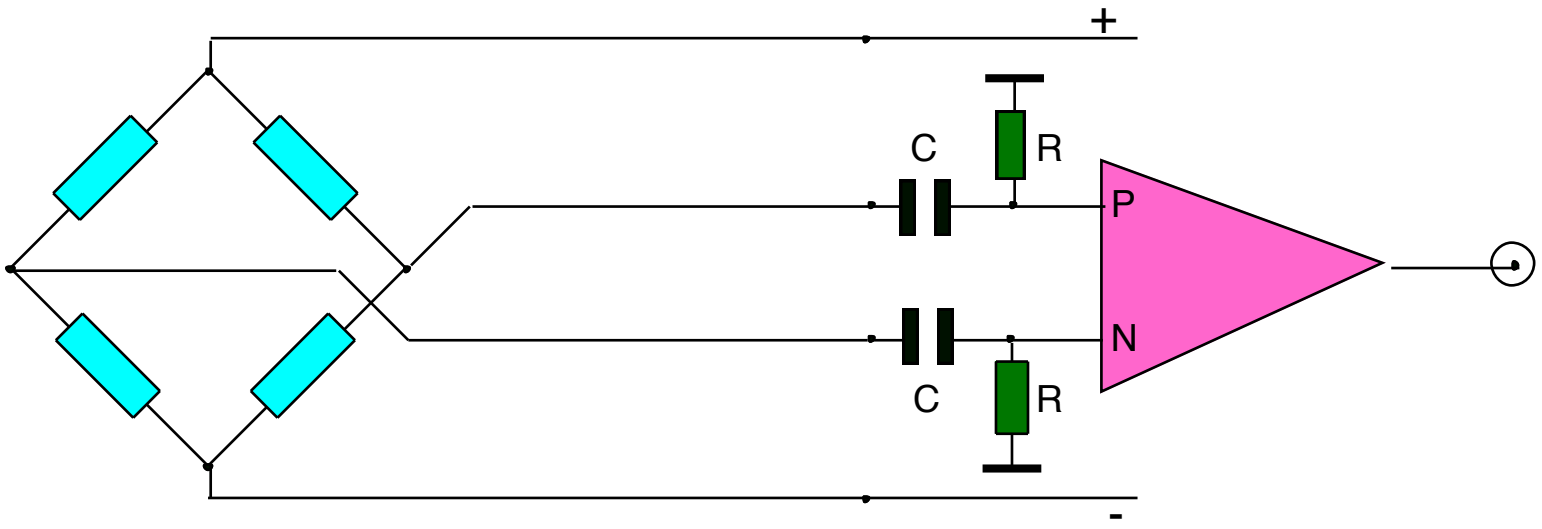
For:

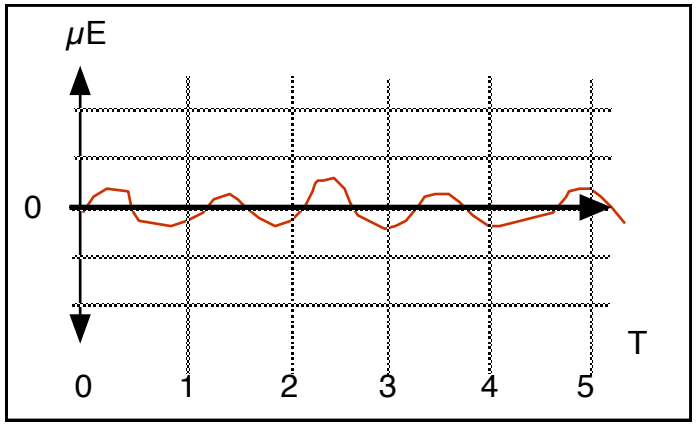
1. Most AC Amplifiers have increased bandwidth.
2. Needs no Balancing - more on this later.
3. No DC drift - so may allow a higher voltage to be used.
4. Possible reduction of single gauge connection to 2 wires.

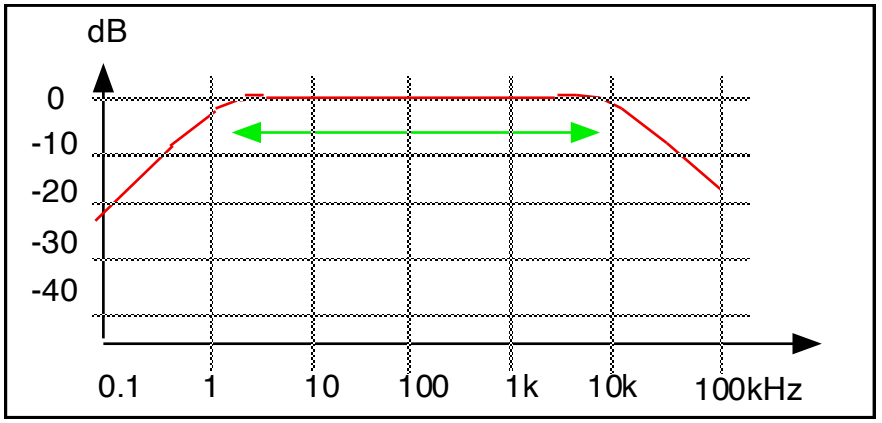
Against:

1. Not all equipments have AC coupling.
2. Fractional Bridges may need external completion.

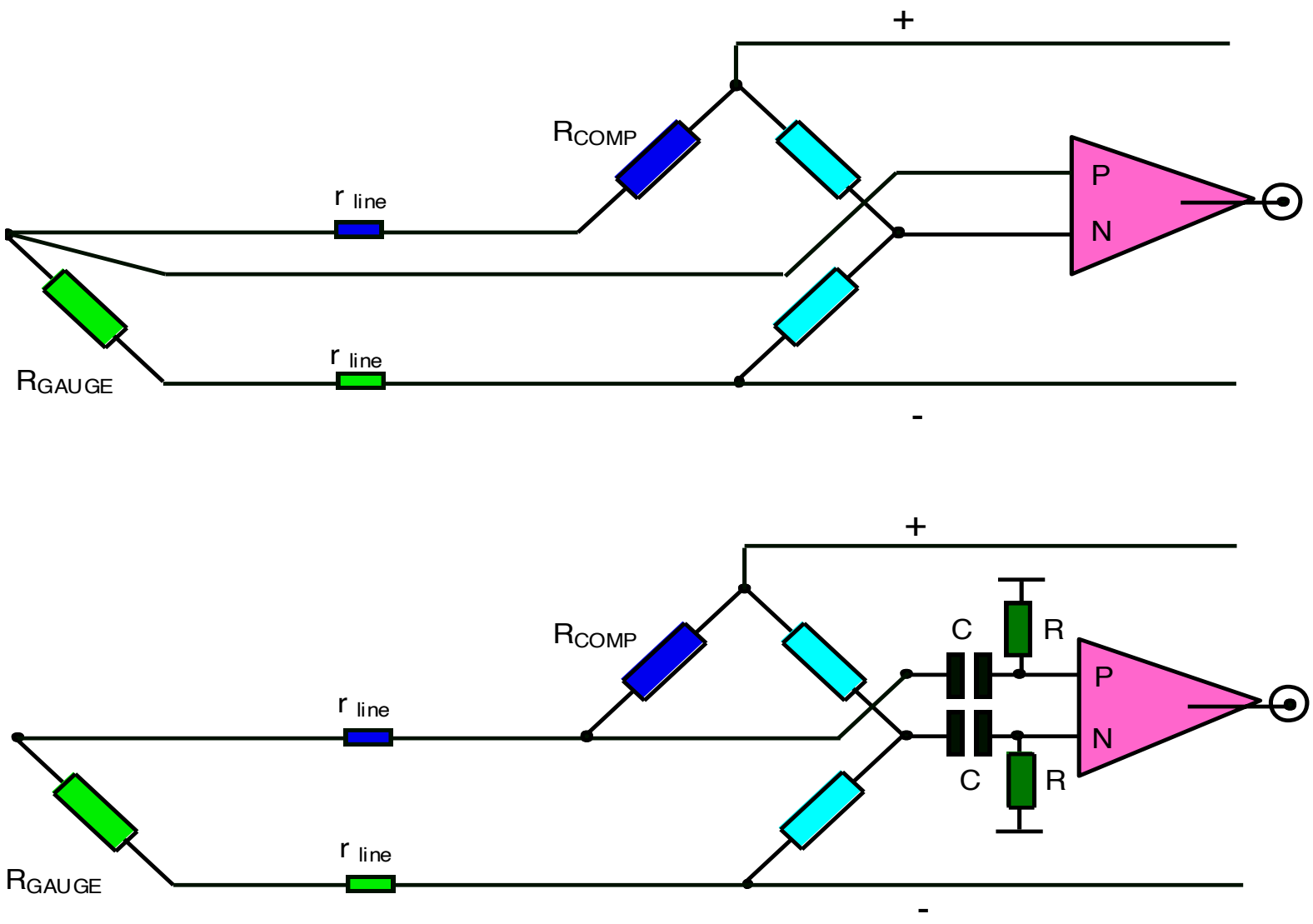
2.1 FULL BRIDGE 'AC' CONNECTION







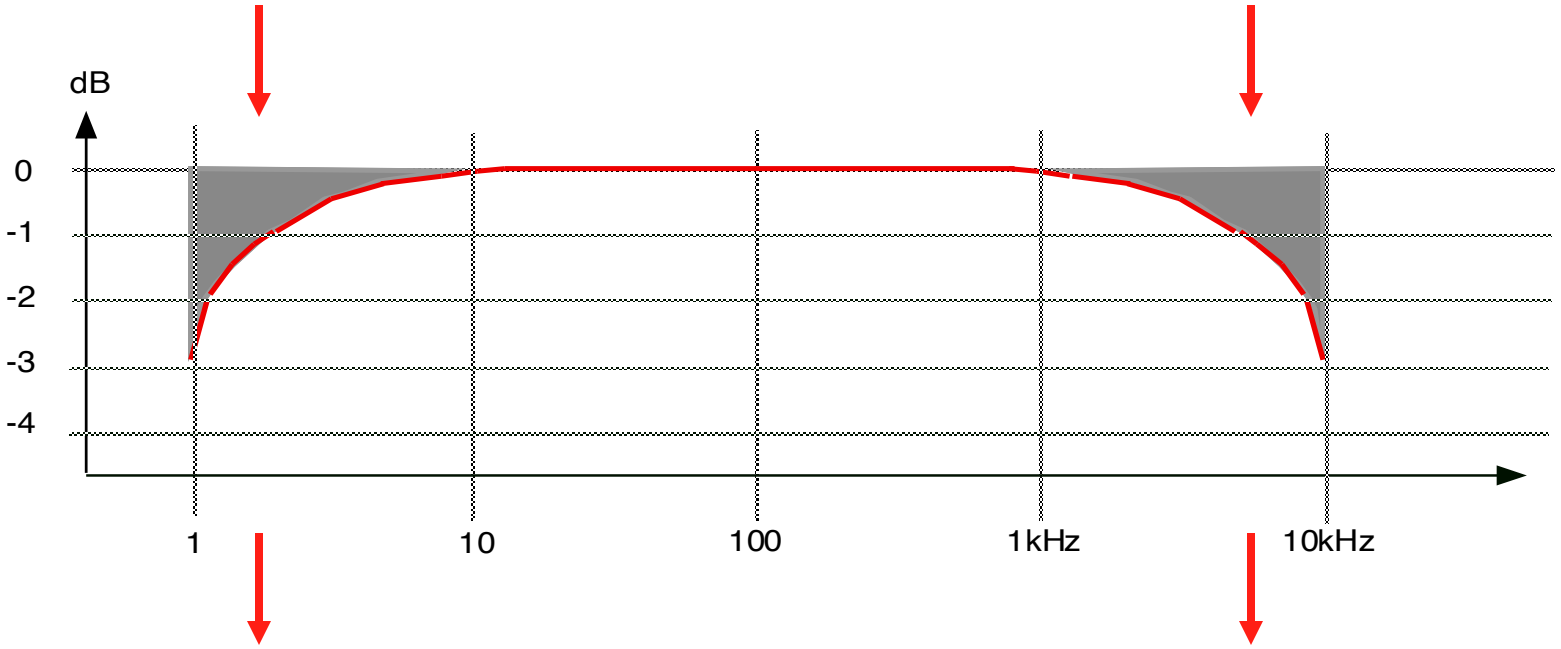
2.2 1/4 BRIDGE CONNECTION



2.3 'AC' CONNECTION : BANDWIDTH

Check this 'grey area':
The response is that of
a 1 pole High Pass filter.

And here:
The response is similar
to a Low Pass filter.



Where Fc = -3dB point =1.6Hz
-0.5dB @ 3Fc = 4.8Hz
-0.1dB @ 7Fc = 11.2Hz

Where Fc = -3dB point =10kHz
-0.5dB @ Fc/3 = 3.3kHz (some are much
-0.1dB @ Fc/7 = 1.4kHz better than this)

2.4 ’AC’ CONNECTION SUMMARY

- Static Strain is not measured.
- Check that you have enough Bandwidth for the measurement:
  AC coupled amplifiers are likely to have more bandwidth as they are intended only for dynamic work.
- You can have too much of a good thing though! Having a bandwidth of 1MHz for signals which have a rise time of 1ms is just opening the amplifier up to interference. FILTER if possible.
- Drift of balance is largely ignored so higher bridge voltage is possible.
- AC coupled amplifiers are very convenient for long term monitoring of dynamic strains, particularly if they must be unattended, as they have no DC component to drift due to temperature or ageing.
- You still need to take care with wiring - more on this later.

3.0 SYSTEM NOISE

System Noise comprises :

1. Noise due to the gauge resistance.
2. Noise due to the bridge supply voltage.
3. Noise due to the electronic processing.
4. Noise due to pickup in wiring.

3.1 NOISE ANALYSIS : GAUGES

1. Noise due to the gauge resistance :

Thermal noise = $\sqrt{4\ k\ t\ b\ r}$ where: r = 350Ω (r)
t = 300 K (27°C)
b = Bandwidth = 10kHz
k = Boltzmanns = 1.38×10^{-23}

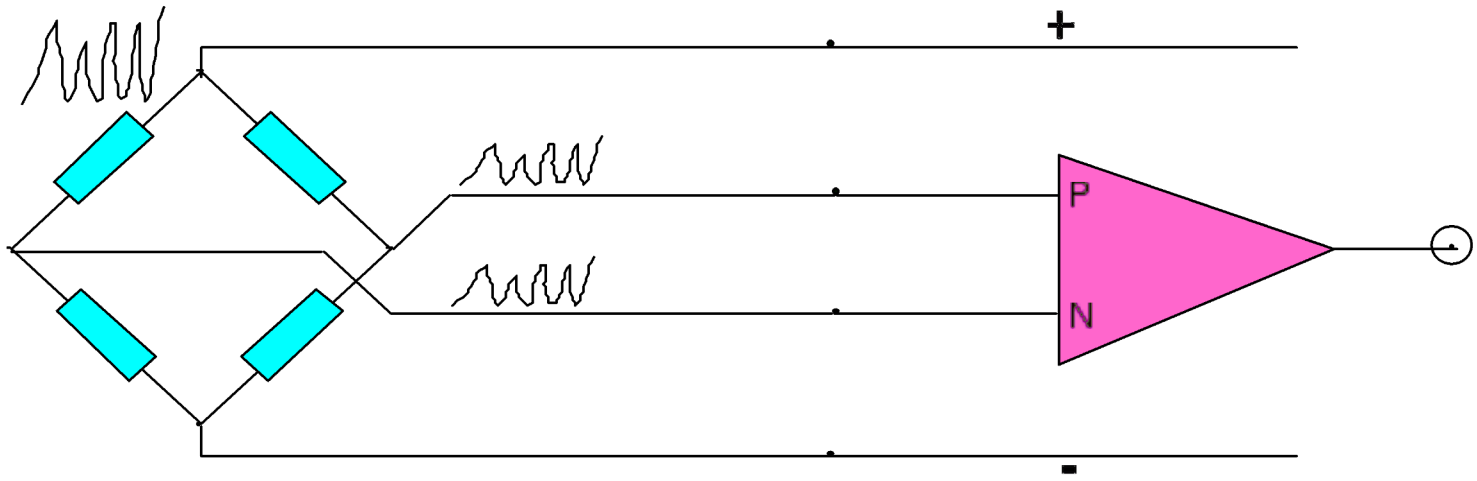
$= \sqrt{4 \times 1.38 \times 10^{-23} \times 300 \times 10 \times 10^{3} \times 350}$
= 240nV RMS …….(x6 for RMS to pk-pk)
= 1.44µV pk-pk

Higher gauge values increase noise but rarely dominate up to 500 ohms. They allow an increase in bridge voltage so improve signal to noise ratio. Too high a value though may limit bandwidth in very high speed systems.

3.2 NOISE ANALYSIS : SUPPLY

2. Noise due to the bridge supply voltage:

Typical bridge voltage noise <100µV pk-pk. At the inputs, 50µV pk-pk.



In a balanced bridge, this presents equally to both inputs.
The amplifier Common Mode Rejection cancels this by (say) 100dB.
The equivalent input noise is thus 50µV /100,000 = 0.5nV.
But: If the bridge is out of balance by 1%, rejection is only 100:1 (40dB).

Noise is now 0.5µVpk-pk.

3.3 NOISE ANALYSIS : ELECTRONICS

3. Noise due to the electronic processing :

Spec for LT1167 gives LF I/P noise as : (0.1 - 10Hz) = 0.28µV pk-pk

and "Spot" noise as : 7.5nV √Hz RMS

For a bandwidth of 10kHz "Spot" noise = $6 \times 7.5 \times 10^{-9} \times \sqrt{10} \times 10^{3}$

= 4.5µV pk-pk

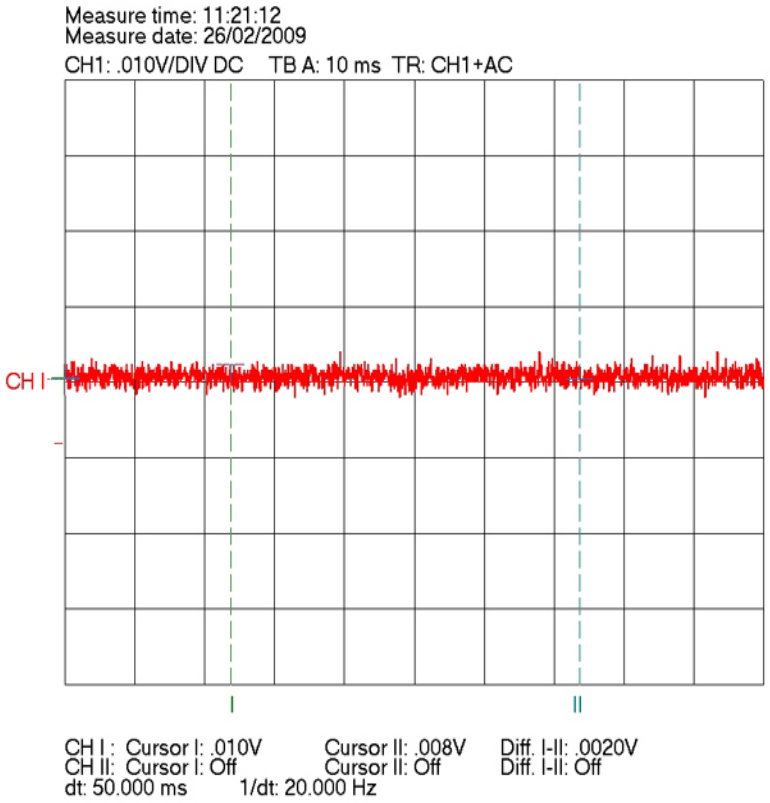
Total input noise = $\sqrt{(4.5^2 + 0.28^2)}$

= 4.51µV pk-pk

3.4 NOISE : EXCLUDING WIRING

Total Noise excluding wiring : = $\sqrt{(1.44^2 + 0.5^2 + 4.51^2)}$

= 4.76µV pk-pk



Seen left : O/P noise of a Bridge amplifier with 10kHz bandwidth using LF1167 and having:

Balanced 350Ω Full Bridge.
Gauge factor = 2.15
Bridge Supply = 10V.
Gain = x1000.

Noise approx 4.76µV pk-pk RTI.

Equiv. to $\frac{4.76 \times 10^{-6}}{10 \times 2.15}$ = 0.22µE pk-pk

3.5 NOISE : WITH INCREASING BANDWIDTH

0.22µE pk-pk Full Bridge with 10V Bridge Supply.

With 2V supply, becomes 1.1µE ... (5 times higher)

If 2V supply & 1/4 bridge, is 4.4µE ... (20 times higher)

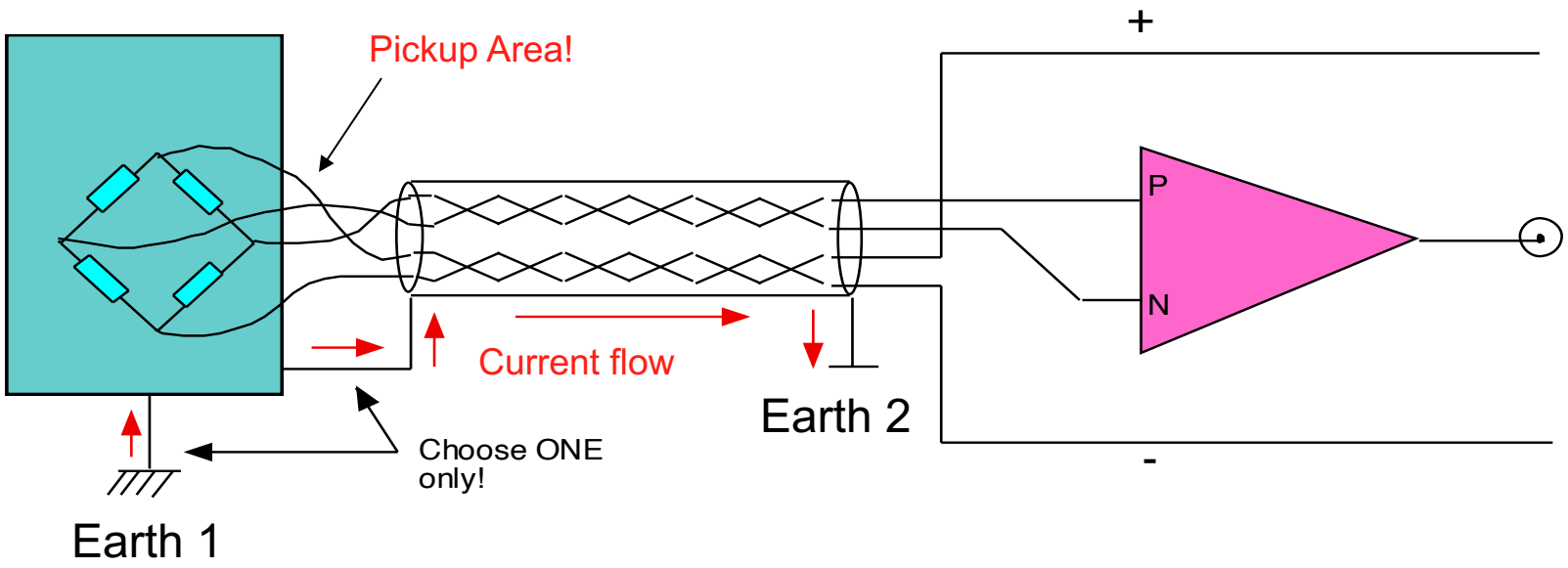
More bandwidth means more noise …

If the 2V supply 1/4 bridge application above allowed a bandwidth increase from 10kHz to 100kHz, the likely increase in noise would be :-

$$\sqrt{(B2 / B1)} = \sqrt{(100/10)} = 3.16$$

$$= 4.4 \times 3.16 = 13.9\mu E$$

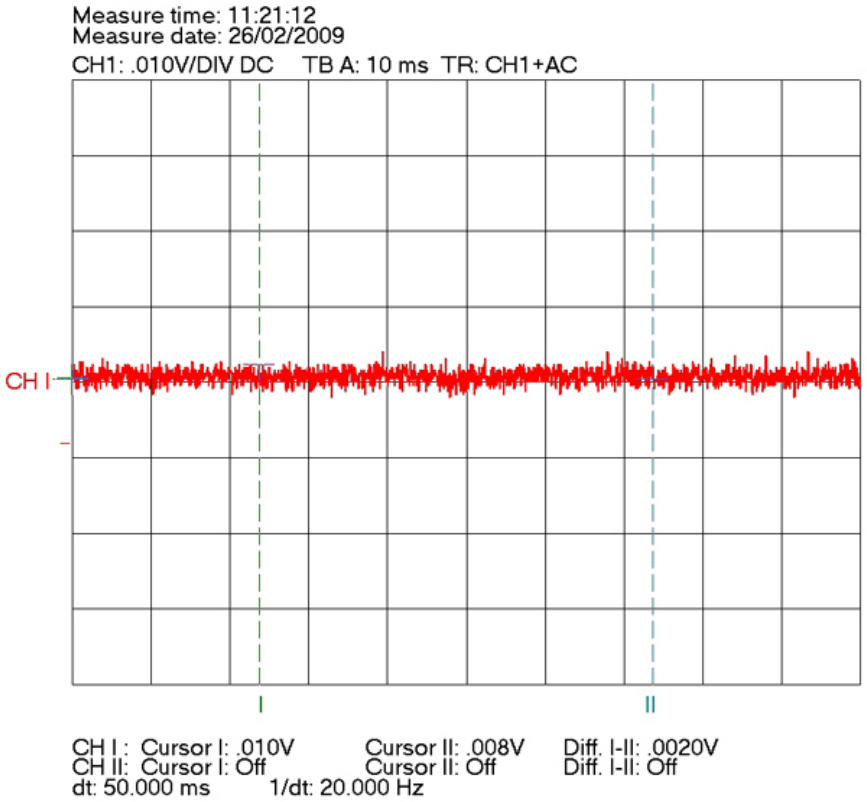
4.0 WIRING : CABLES



- The input wiring is twisted and screened.
- If the specimen mounting area is conductive, is it earthed?

  If not, you could do this via the screen of the cable, but don't earth twice.

4.1 WIRING : IDEAL RESULT

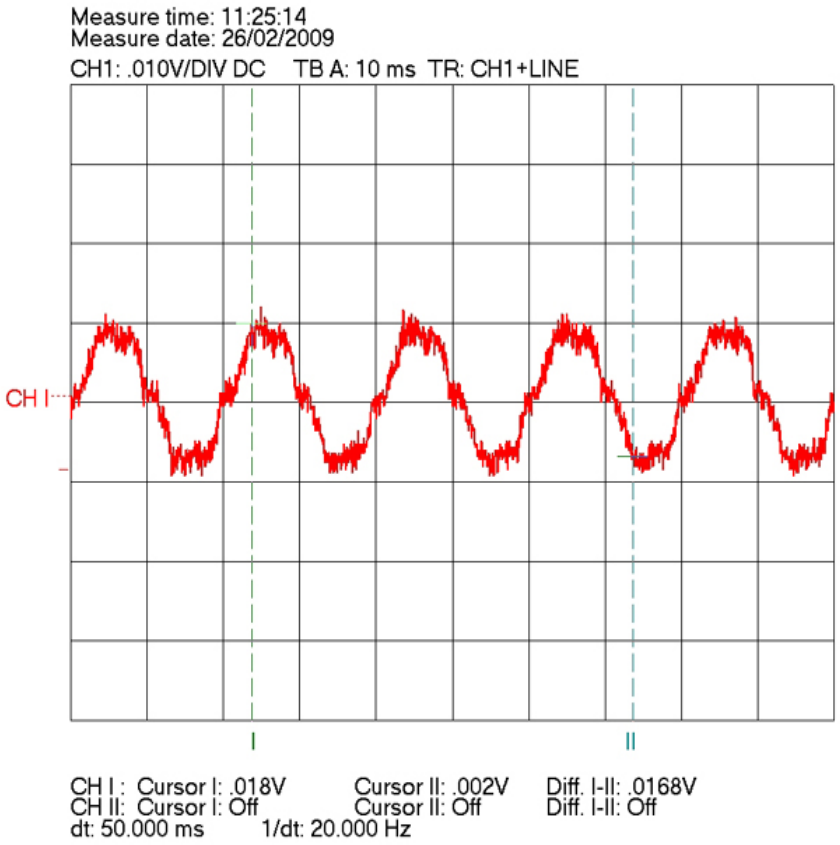


Pickup free!

Sources:

- Good wiring layout
- Good cables, twisted & screened
- Good earthing.

4.2 WIRING : ELECTROSTATIC PICKUP



Electrostatic pickup

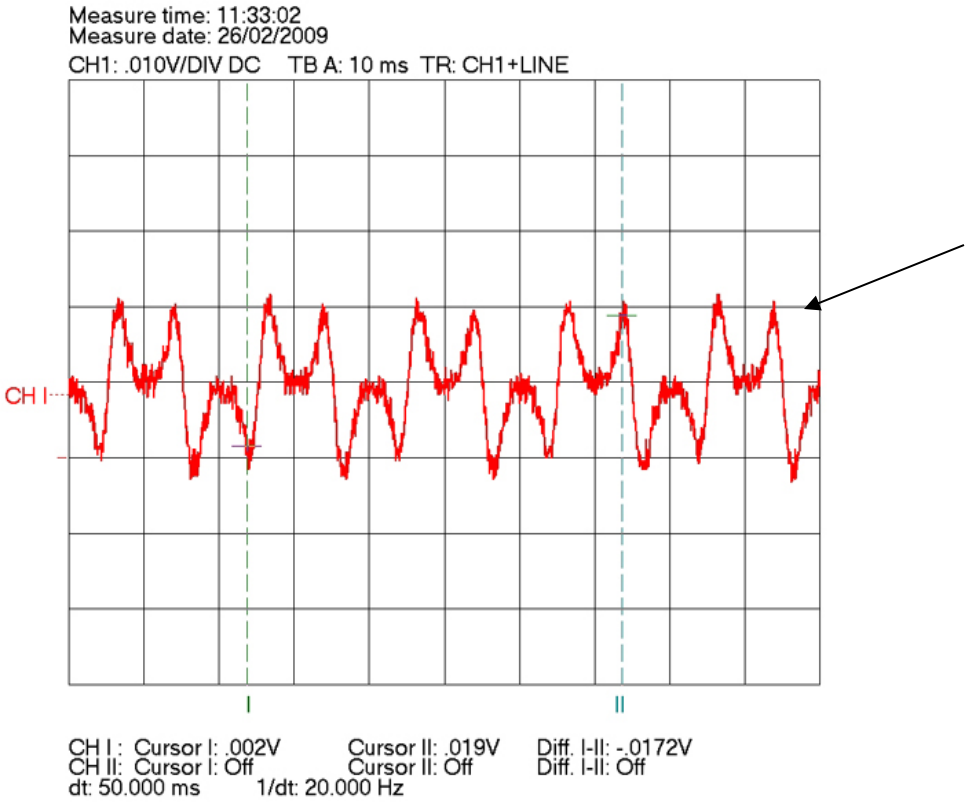
Sources:

50 or 60Hz mains wiring making capacitive coupling to gauge wiring.

Fix it by:

- Routing cables away from mains wiring.
- Screening input connections.
- Twisting input connections.
- Keeping unscreened lengths short and running them on the earthed structure.

4.3 WIRING : ELECTROMAGNETIC PICKUP



Electromagnetic pickup

Sources:

Transformers, AC Motors, Solenoids (magnetic devices).

20µV RTI

For a 1/4 bridge with 2V supply

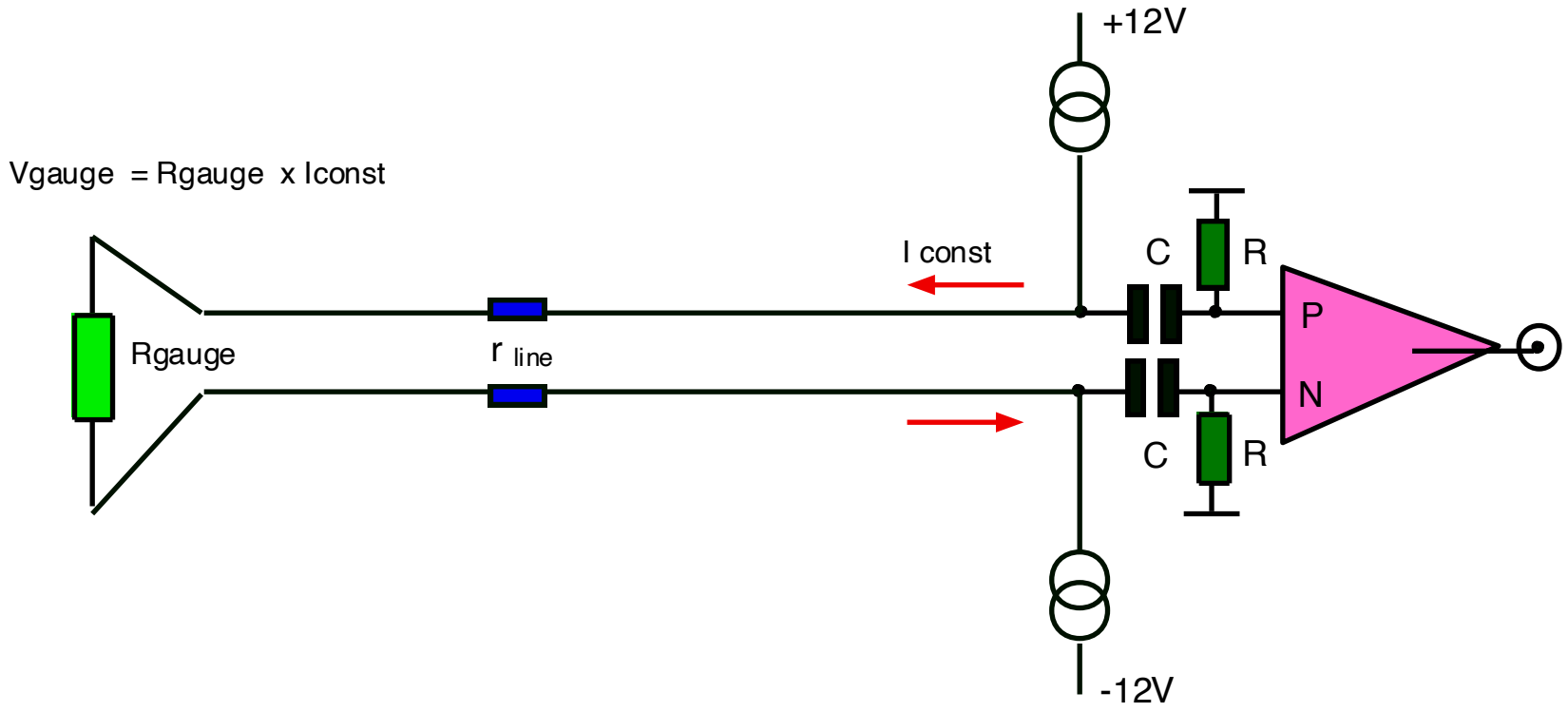
$$\frac{20 \times 10^{-6} \times 4}{2 \times 2.15} = 18.6\mu E \text{ pk-pk}$$

And it can be worse than this, >50µV (47µE) pickup is not uncommon!

4.4 WIRING SUMMARY

- Use screened, twisted cable wherever possible.
- Try to route wiring away from interference sources.
- Keep unshielded sections short. If possible, run them on earthed metal work for shielding.
- Is the metalwork earthed? - but try not to earth it twice!
- Still got problems? Identify your interference source from its pickup form. Is it electromagnetic or electrostatic pickup?
- Additional shielding may help to reduce electrostatic pickup, but electromagnetic pickup is hard to stop in this way and requires heavy ferrous shielding.
- Completing the bridge at the specimen rather than at the amplifier may be advantageous, as a full bridge has symmetrical wiring.

5.0 DYNAMIC CONSTANT CURRENT CONNECTION



“Standard” 1/4 bridge	Dynamic Constant Current
$\partial V = \frac{Vgauge \times GF \times E}{2}$	$\partial V = Vgauge \times GF \times E$

5.1 FE-859-TA DYNAMIC AMPLIFIER SYSTEM

- DC to 100kHz Bandwidth.
- Voltage & Dynamic Constant Current.
- Static & Dynamic measurements.
- Digital Auto-Zero (auto-balance).
- Active filter.
- Shunt and voltage cal.
- Network via Ethernet or RS232.
- Can be expanded for Diff. & SE
- Charge, and IEPE inputs.

DYNAMIC AMPLIFIERS & SYSTEM NOISE FINAL SUMMARY

- Check that you have ‘enough’ bandwidth, but remember that noise increases with the square root of the bandwidth.
- The thermal noise of the gauge is rarely dominant, so 350Ω gauges with higher bridge supplies may offer an advantage.
- Keep an eye on DC balance or Bridge Supply noise. If the bridge supply is noisy, a severe unbalance can add noise to the signal.
- Pickup in wiring can dominate, particularly if bandwidth is moderate when noise *should* be low.
- The Dynamic Constant Current technique improves signal quality, simplifies wiring, eases calibration and is tolerant of Zener Barriers and cable resistance.