Shunt Calibration for Dummies; a Reference Guide

by

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ABSTRACT

Shunt Calibration is a technique for simulating strain in a piezo-resistive strain gage Wheatstone bridge circuit by shunting one leg of the bridge. The bridge may be internal to a discreet transducer or composed of separately applied strain gages. The resulting bridge output is useful for calibrating or scaling instrumentation. Such instrumentation includes digital indicators, amplifiers, signal conditioners, A/D converters, PLC's, and data acquisition equipment. Care must be taken to understand the circuits and connections, including extension cables, in order to avoid measurement errors.

1. What is Shunt Cal ?

- Shunt Calibration = Shunt Cal = SCAL = RCAL
- A means of calibrating or verifying instrumentation by simulating a physical input.
- The simulation is accomplished by shunting one leg of a Wheatstone bridge circuit.
- Not a means of calibrating a transducer.
- A “poor man’s” mV/V simulator.

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2. A Good Simulator is Superior to Shunt Cal

- A simulator is not strain sensitive.
- Resistor ratios are less temperature sensitive.
- Thermal emf errors are minimized by design.
- Symmetrical shunting produces less common mode error.
- Provides specific and convenient mV/ V values.
- Provides a true zero output.
- Has no toggle.
- Shunt resistor doesn’t get lost.
- A calibration history can be maintained.

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3. Shunt Cal has some advantages

- Low cost.
- The bridge circuit is already there.
- Need to make and break cable connections can be avoided.
- Can be applied conveniently and at any time and during test programs.

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4. About Formulae in this Paper

- The formulae herein are derived by the author and he is responsible for any errors.
- Rs = Value of shunt resistor.
- Rb = Bridge resistance represented by single value.
- Vs = Simulated output at signal leads in units of mV/V.
- Vs is always net (the difference between the shunted and unshunted readings or similarly the difference between the switch-closed and switch-open readings).
- " = " means mathematically exact.
- " ≈ " means close enough for practical purposes.
- Infinite input impedance of instrumentation is assumed.

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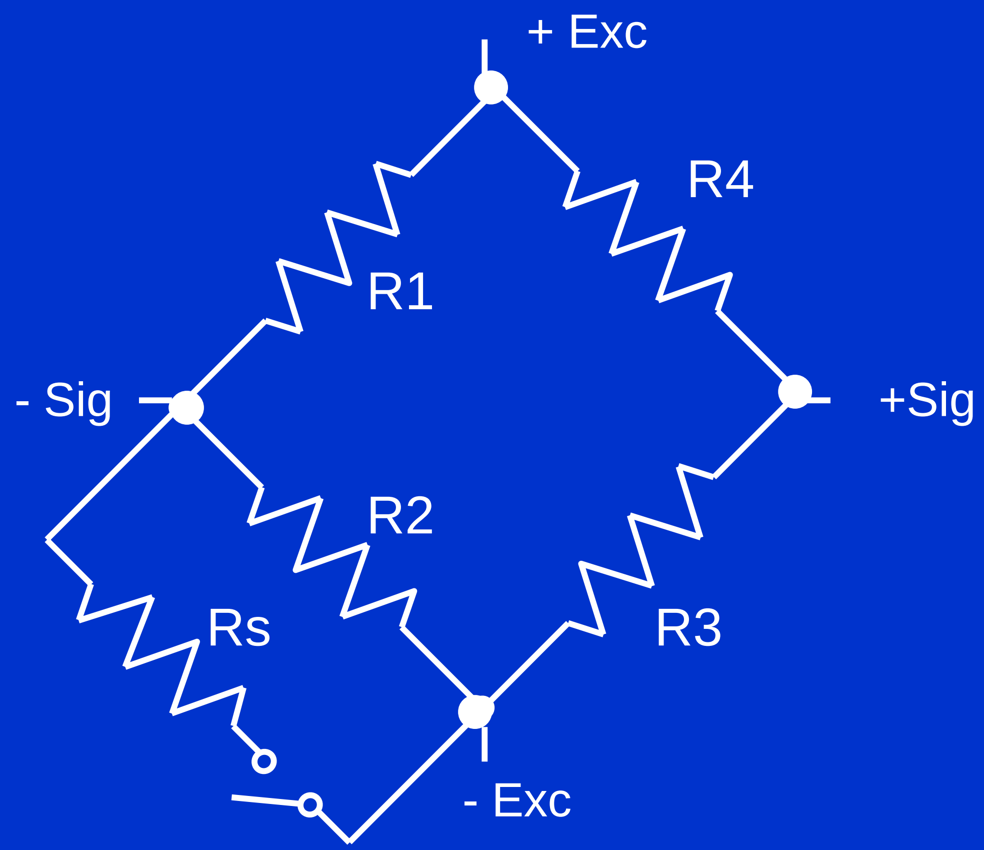
4. About Formulae (continued)

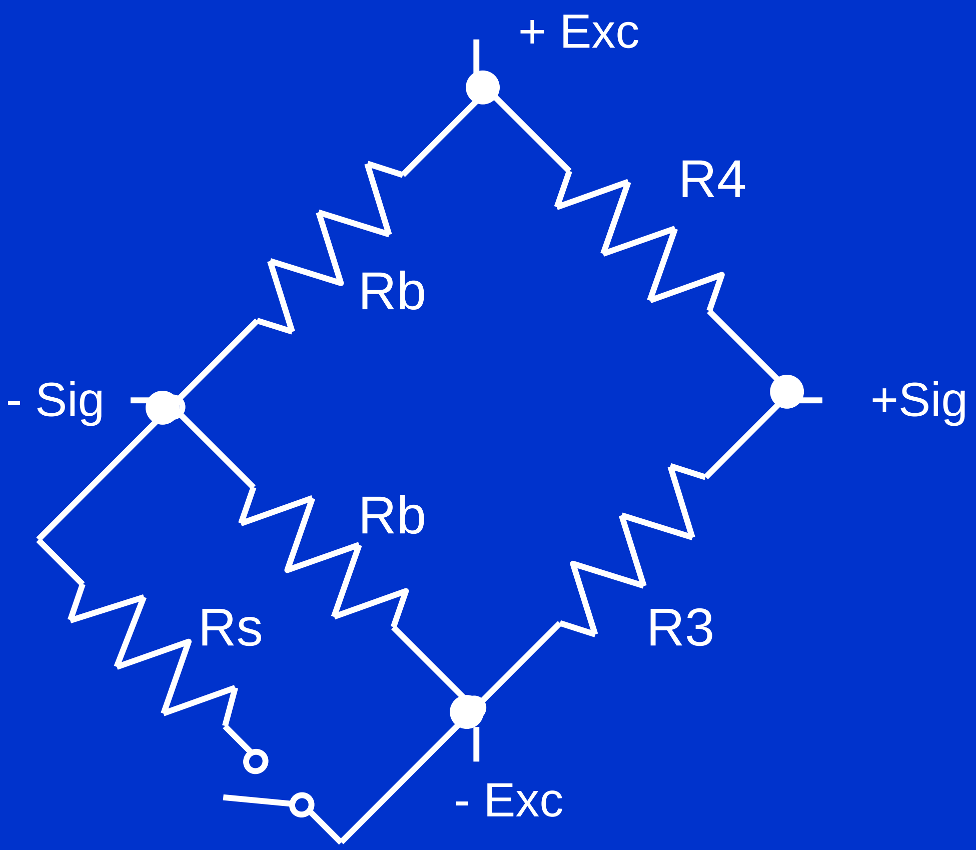
- In each circuit type, only one leg of the bridge is shown shunted, for simplicity. But the formulae apply as well to the opposite leg if the resistor numbers are placed in the formula according to position. They also apply to the adjacent legs if resistor numbers are placed according to position and polarity of Vs is reversed.

5. Basic Bridge Circuit



$$Vs = \frac{1000\,R2}{Rs\left(\frac{R1}{R2} + \frac{R2}{R1} + 2\right) + R1 + R2}$$

Simplified Basic Bridge Circuit, R1=R2=Rb



$$Vs = \frac{250}{\frac{Rs}{Rb} + 0.5}$$

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Basic bridge circuit examples

Rb (ohm)	Rs (ohm)	Vs (mV/V)
350	30,000	2.89975
350	40,000	2.17797
350	59,000	1.47866
350	60,000	1.45409
700	120,000	1.45409
1000	120,000	2.07469

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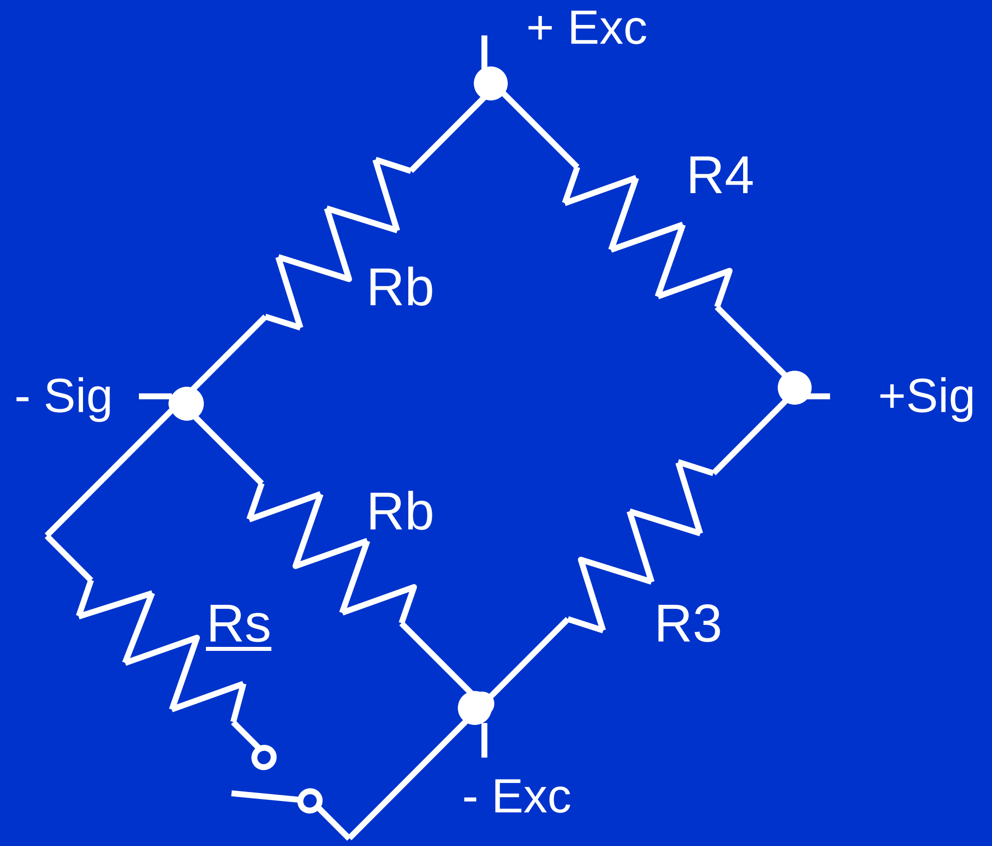
Basic Bridge Formula Inverted to solve for Rs

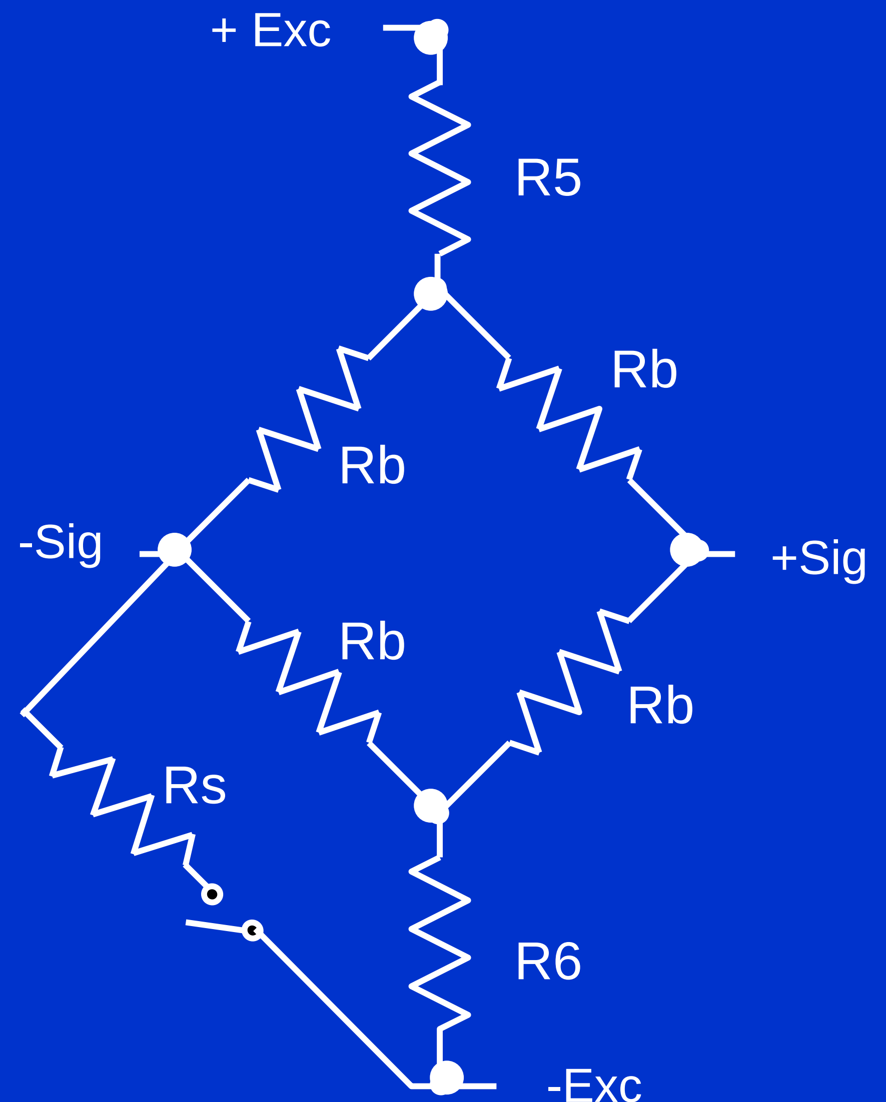


$$Rs = Rb\left(\frac{250}{Vs} - 0.5\right)$$

Basic circuit inverted formula examples

Rb (ohm)	Vs (mV/V)	Rs (ohm)
350	1	87,325
350	2	43,575
350	3	28,992
700	2	87,150
700	3	57,983
1000	3	82,833

6. Bridge With Series Trim or Compensation Resistors



$$Vs \approx \frac{250}{\frac{Rs}{Rb}+0.5}\left(1-\frac{R6+R5}{4Rs}\right)\left(1+\frac{R6-R5}{R6+R5+Rb}\right)$$

$$V \approx \frac{250}{\frac{Rs}{Rb} + 0.5}\left(1 - \frac{R6 + R5}{4Rs}\right)\left(1 + \frac{R6 - R5}{R6 + R5 + Rb}\right)$$

Nominal term | Summation term | Difference term

This formula for the series resistors case is interesting because it shows that if R5 = R6, Vs is nearly the same as if R5 = R6 = 0. This fact allows a batch of transducers with variations in natural loaded outputs to be trimmed with series resistors to a standard output and all will have a similar Vs.

Series resistor circuit examples

Rb (ohm)	Rs (ohm)	R5 (ohm)	R6 (ohm)	Vs (mV/V)
350	60,000	0	0	1.45409
350	60,000	50	50	1.45349
350	60,000	0	50	1.63551
350	60,000	50	0	1.27207
350	60,000	175	175	1.45198
700	60,000	0	100	3.26086
700	60,000	100	200	3.18574

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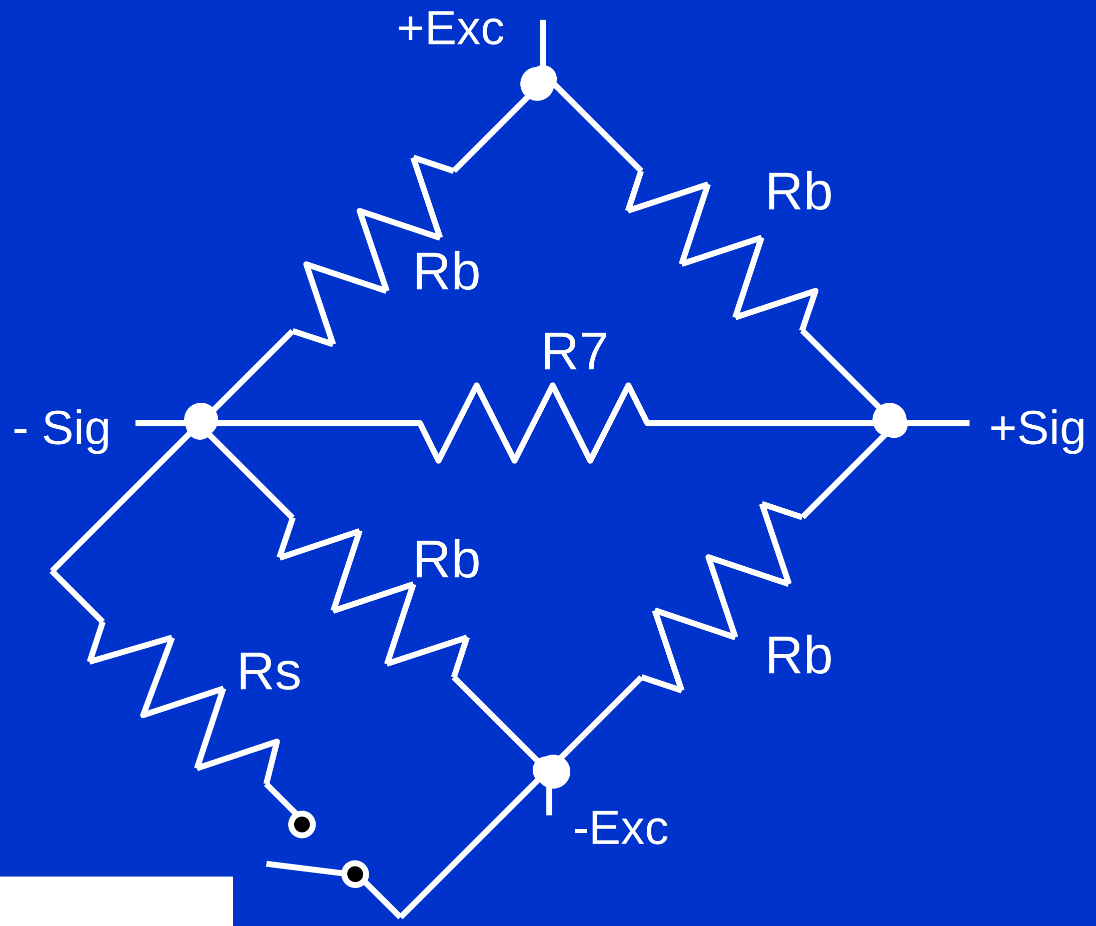
7. Bridge With Parallel Trim or Compensation Resistor



$$Vs = \frac{250}{\left(\frac{Rs}{Rb}+0.5\right)\left(1+\frac{Rb}{2R7}\right)+\frac{Rs}{2R7}}$$

Parallel resistor circuit examples

Rb (ohm)	R7 (ohm)	Rs (ohm)	Vs (mV/V)
350	4	60,000	1.45409
350	100,000	60,000	1.44903
350	10,000	60,000	1.40499
350	1,000	60,000	1.07751
350	350	60,000	0.72758
350	350	30,000	1.45198

8. How Does Tolerance of Rb and of Rs affect Vs ?

To a close approximation for all of the circuits above with reasonable values,

- Vs is proportional to the value of Rb and
- Vs is inversely proportional to the value of Rs.

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9. What Errors are Contributed by Extension Cables ?

It often happens that initial shunt calibration data is recorded on a particular bridge and then in subsequent tests an extension cable has been added between the bridge and the instrument with Rs located at the instrument. It is useful to know the resulting error.

In the following discussion Rc represents the resistance of one conductor of a cable made of multiple similar conductors.

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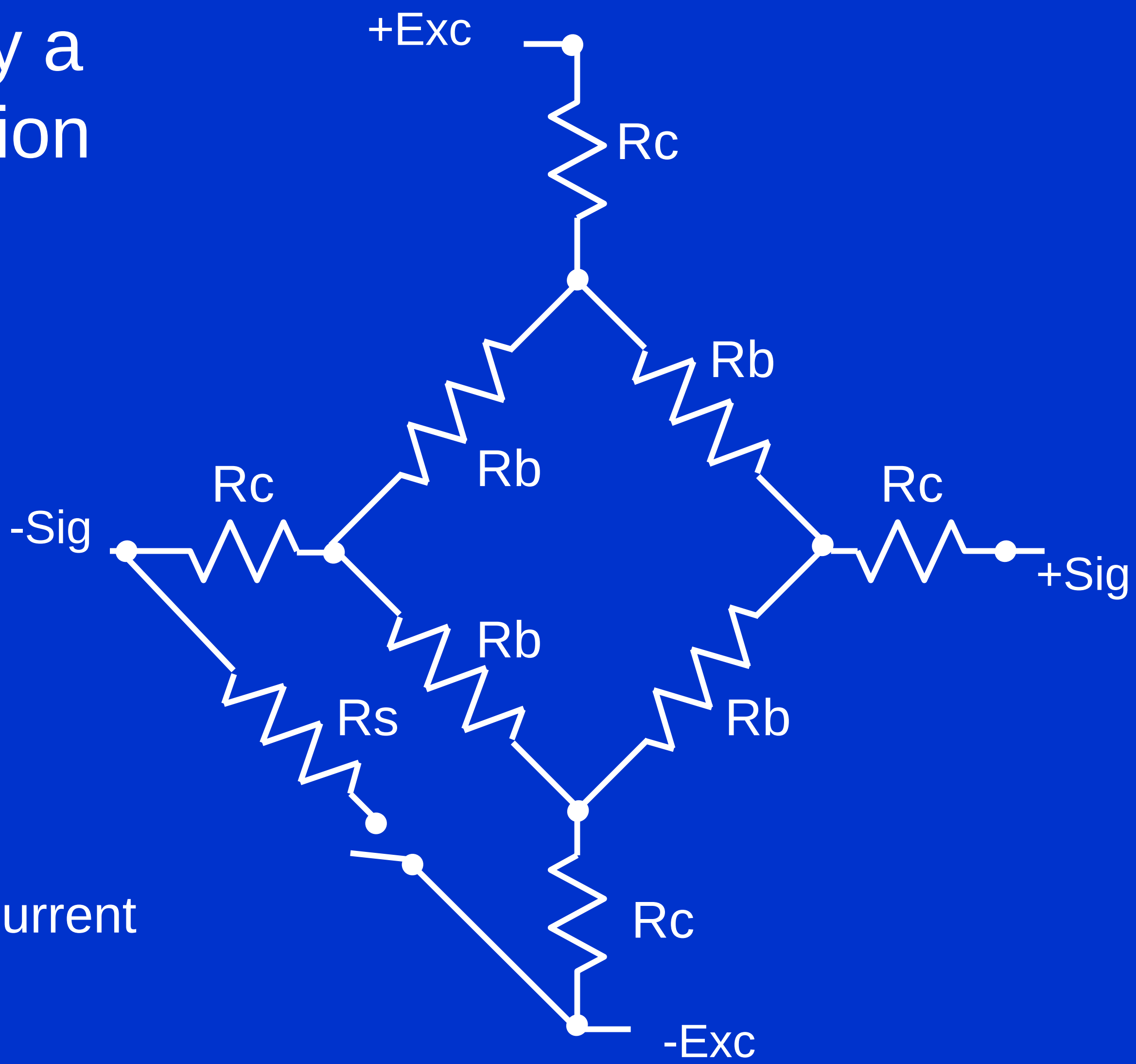
Error contributed by a 4-conductor extension cable



- Error is due primarily to current flow in –Sig lead.
- Vs error = 500 Rc / Rs (in units of mV/V).
- Error is always same polarity as Vs.

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4-Conductor Error Examples

Based on 10 ft cable length

Conductor Gauge	Rc (ohm)	Rb (ohm)	Rs (ohm)	Nom Vs (mV/V)	Vs Error (mV/V)	Vs Error (%Vs)
22	0.16	350	30,000	2.8998	0.0027	+0.09
22	0.16	350	60,000	1.4541	0.0013	+0.09
28	0.65	350	60,000	1.4541	0.0054	+0.37
30	1.03	350	60,000	1.4541	0.0086	+0.59
30	1.03	700	60,000	2.8998	0.0086	+0.30
30	1.03	700	120,000	1.4541	0.0043	+0.30

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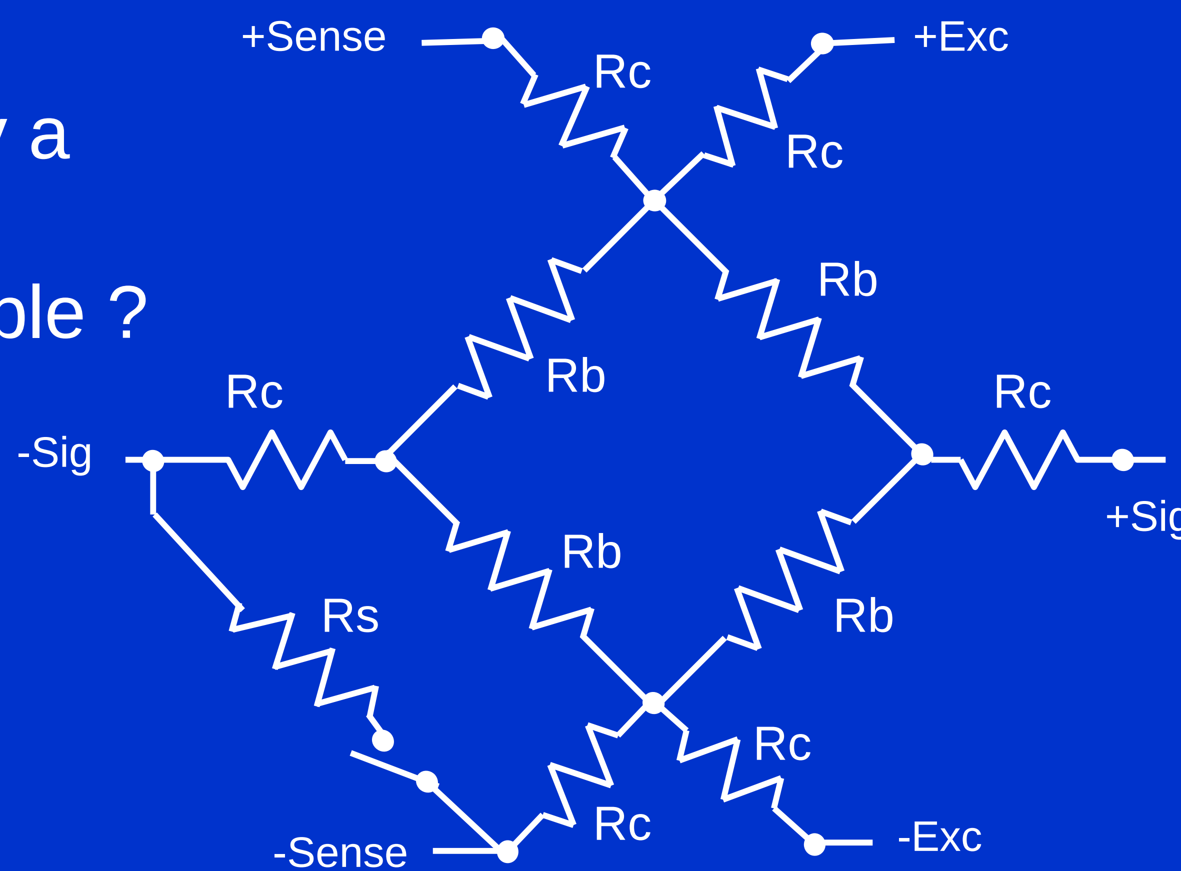
Caution !

If Vs is being converted to physical units, remember that the 4-conductor extension cable changes output of the circuit by the factor

$$\frac{Rb}{Rb + 2Rc}$$

If Rc is not accounted for in the conversion, the error compounds the Vs error, doubling it as a % of reading !

10. What Error is Contributed by a 6-Conductor Extension Cable ?



- Same error in Vs as for 4-conductor extension cable.
- No error in physical load output due to Rc in Exc leads.
- Remote sensing of excitation is the benefit of a 6-conductor cable.

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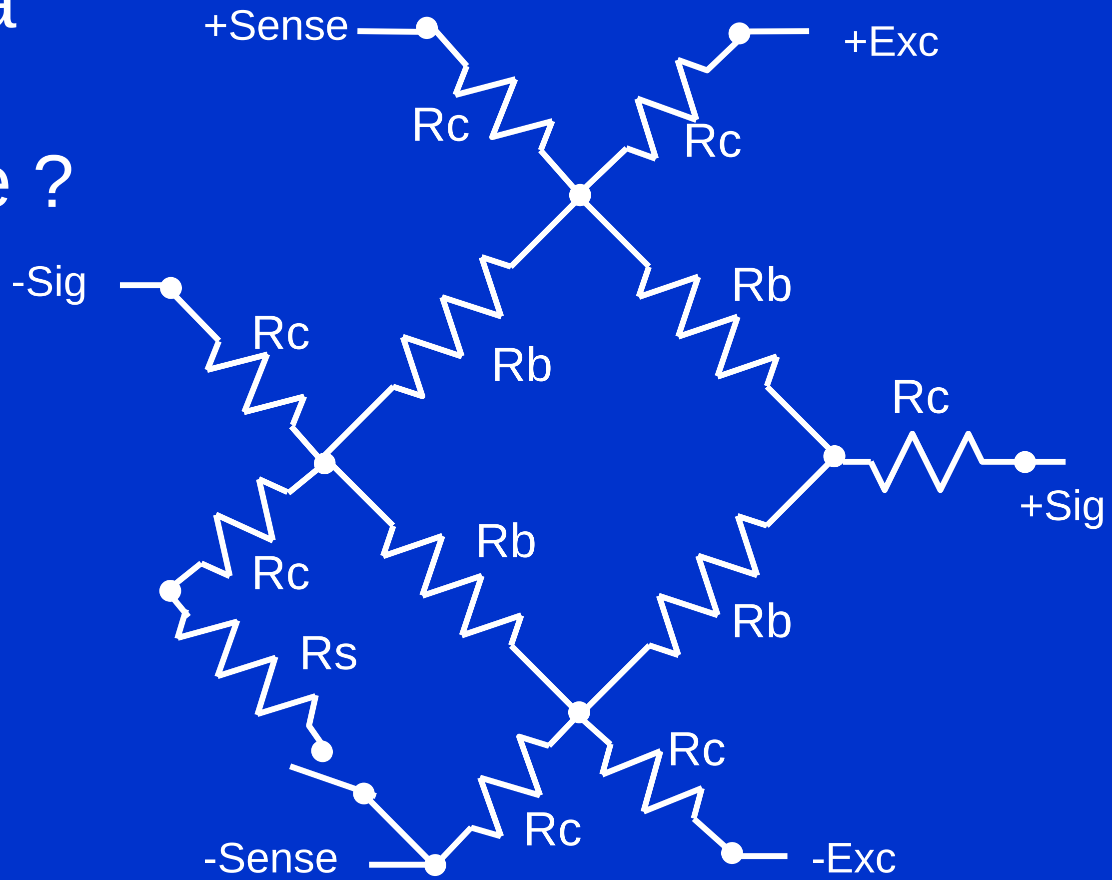
11. What Error is Contributed by a 7-Conductor Extension Cable ?



- Only error is Rc adding to Rs for total shunt =Rs+Rc.
- Error is negligible for all practical purposes.

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12. Why are 8-Conductor Cables Sometimes Used ?

- To allow shunt connection to either –Sig or + Sig and have negligible error.

- 7-Conductor and 8-Conductor cables solve the extension cable error problem.

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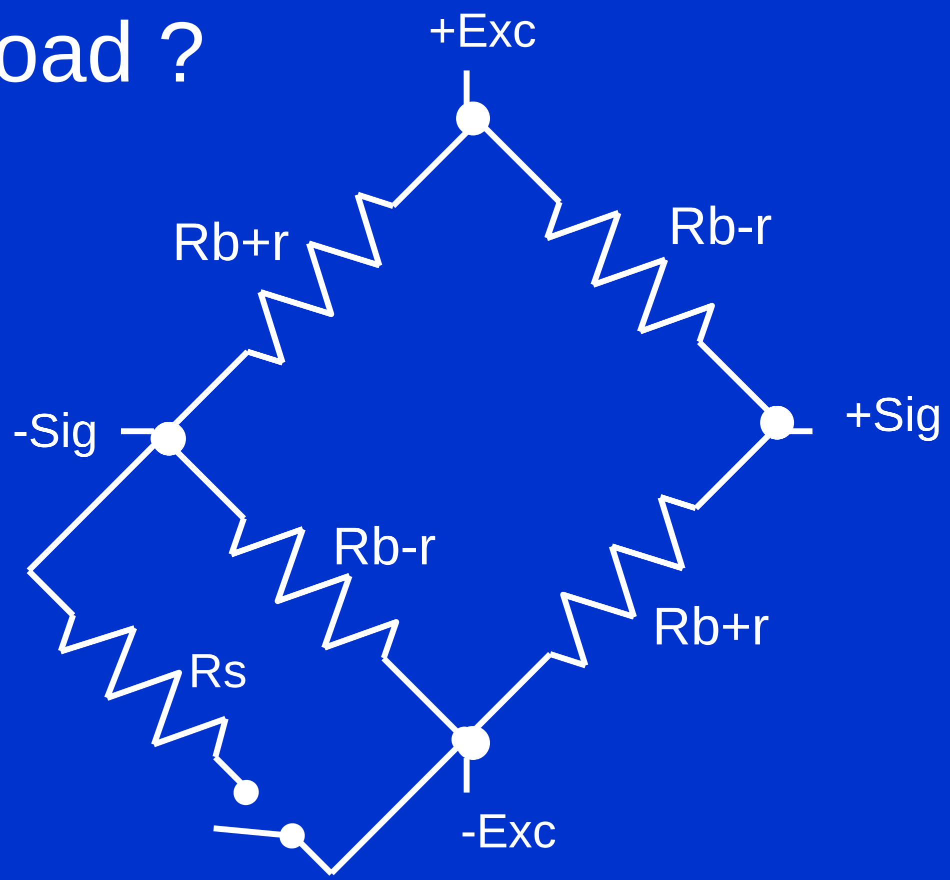
13. What Error in Shunt Cal is Caused by a Physical Load ?



- Analyze by assuming a fully active basic bridge circuit.
- r = change in gage resistance due to strain.
- Error in Vs is proportional to r / Rb.

Error due to Physical Loads, Examples

(Assuming all legs equally active)

Rb (ohm)	Rs (ohm)	Vs without load (mV/V)	Physical Load (mV/V)	r (ohm)	Vs with load (mV/V)	Error (mV/V)	Error %
350	60,000	1.45409	0	0	1.45409	0	0
350	60,000	1.45409	+1	0.35	1.45264	-0.00146	-0.10
350	60,000	1.45409	+2	0.70	1.45118	-0.00291	-0.20
350	60,000	1.45409	-2	-0.70	1.45699	+0.00290	+0.20
350	60,000	1.45409	-1	-0.35	1.45554	+0.00145	+0.10
700	60,000	2.89975	-1	-0.70	2.90265	+0.00290	+0.10

Generalized Rule: For any Rb and Rs,

Error in % = - 0.1 X Physical Load in mV/V

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14. What is the Effect on Shunt Cal of a Permanent Zero Balance Shift ?

- If all legs are equally active and somewhat equally shifted in resistance, as is often the case with a mild physical overload, error in Vs follows the same analysis as in paragraph 13 above.

- It is wise to assume that any significant permanent zero shift invalidates a prior Shunt Cal.

15. What is the Effect on Shunt Cal of Transducer Toggle ?

- Toggle is a reversible change in bridge zero resulting from the most recent loading changing from tension to compression or vice versa.
- The error in Vs follows the same analysis as in paragraph 13 above.
- Toggle seldom exceeds 0.01 mV/V even for load excursions as high as +/- 4 mV/V.
- Therefore error in Vs seldom exceeds 0.001% for any Rb or Rs.
- The error is normally negligible.

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16. Is There Reason to Prefer Any Particular Leg of the Bridge to Shunt ?

- Probably not.
- In terms of stability and repeatability, all legs are contributing equally to a shunt measurement.
- R5 and R6 contribute equally to Vs for shunt measurement on any leg regardless of their values. Remember paragraph 6 !

$$Vs \approx \frac{250}{\frac{Rs}{Rb}+0.5}\left(1-\frac{R6+R5}{4Rs}\right)\left(1+\frac{R6-R5}{R6+R5+Rb}\right)$$

17. Can a Value for Vs be Calculated for any Rs, Knowing Only Rin and Rout of the Bridge ?

- Only approximately because Rin and Rout only approximate the value of R1, R2, R3, or R4 in the basic circuit.
- With tolerances typical of strain gages and bonding processes in transducer production, 0.25% is about the uncertainty of a calculation for Vs with the basic circuit.
- It gets worse if R5, R6, or R7 are present.

18. Where May the Shunt Resistor Be Located ?

a. Internal to a transducer or permanently wired to a bridge circuit.

- Resistor tolerance not important.
- Resistor should have low temperature coefficient of resistance (TCR).

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b. Internal to an Instrument.

- Low resistor tolerance is important unless a bridge and specific instrument are always used together.
- TCR should be low.

HRBSC

9840

These high end instruments have 0.01% Low TCR Internal Shunt Cal Resistors in two different values. Instruments may be substituted without significant error.

9830

9820

These lower cost instruments have 1% tolerance Shunt Cal Resistors.
For good Vs measurements, instruments should not be substituted.

DCA

These lower cost signal conditioning modules have 1% tolerance Shunt Cal Resistors and a manual switch permanently installed. For good Vs measurements, instruments should not be substituted.

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c. External resistor, portable.

- Substitutability depends on tolerance.
- Potential for high accuracy.
- Potential to get lost or mixed.

d. External, laboratory instrument.

- 0.01% tolerance available.
- Good substitutability.

Special 3-bank decade resistor, tests up to 3 bridges simultaneously.
1 ohm to 1111 Kohm, 0.01 % tolerance.

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19. What Shunt Cal Repeatability Can Be Expected From Modern Transducers ?

<u>Procedure for a repeatability test performed</u>

- 100 Klbf Load Cell specimen loaded in compression.
- 12 test cycles of 4 mV/V hydraulically applied physical load and 1 mV/V Shunt Cal on two bridge legs.
- Rb = 350 ohm, Rs = 88750 ohm, 20 ppm/°C, internal to load cell.
- Measurements over 3 days.
- Interface Gold Standard HRBSC instrumentation.

<u>Results of test</u>

- Std Dev of physical load measurement: 0.004%.
- Std Dev of Shunt Cal: 0.001% pos, 0.001% neg.

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Shunt Calibration Repeatability Data

Model: 1232BKN-100K
S/N: 103014 Bridge A Internal Shunt Resistor: 88.75 Kohm
Standards usec STD-16,BRD4,BRD1

Sequence	1	2	3	4	5	6	7	8	9	10	11	12	Std Dev
Date	3-26-1999,	3-26-1999,	3-26-1999,	3-26-1999,	3-26-1999,	3-26-1999,	3-26-1999,	3-26-1999,	3-26-1999,	3-26-1999,	3-29-1999,	3-29-1999,	
Time	16:44:11	16:51:29	16:56:25	17:01:10	17:11:22	17:17:24	18:03:14	18:08:02	20:33:34	20:37:16	07:28:39	07:33:36	
Temp F	75	75	75	75	75	75	75	75	75	75	75	75	
Humidity %	32	32	32	32	32	32	32	32	32	32	32	32	
Load mode	COMPR	COMPR	COMPR	COMPR	COMPR	COMPR	COMPR	COMPR	COMPR	COMPR	COMPR	COMPR	
Units	Klbf	Klbf	Klbf	Klbf	Klbf	Klbf	Klbf	Klbf	Klbf	Klbf	Klbf	Klbf	
LOAD (Klbf):													
0	-0.01424	-0.01429	-0.01429	-0.01432	-0.01433	-0.01436	-0.01340	-0.01343	-0.01333	-0.01341	-0.01331	-0.01342	
20	-0.81384	-0.81388	-0.81394	-0.81402	-0.81406	-0.81403	-0.81302	-0.81309	-0.81303	-0.81305	-0.81293	-0.81306	
40	-1.61358	-1.61367	-1.61370	-1.61382	-1.61385	-1.61385	-1.61283	-1.61283	-1.61280	-1.61286	-1.61271	-1.61287	
60	-2.41373	-2.41383	-2.41380	-2.41390	-2.41392	-2.41390	-2.41297	-2.41294	-2.41284	-2.41296	-2.41271	-2.41284	
80	-3.21476	-3.21483	-3.21484	-3.21486	-3.21486	-3.21483	-3.21399	-3.21403	-3.21392	-3.21395	-3.21365	-3.21373	
100	-4.01617	-4.01619	-4.01616	-4.01620	-4.01613	-4.01609	-4.01558	-4.01549	-4.01537	-4.01530	-4.01510	-4.01505	
40	-1.61607	-1.61617	-1.61616	-1.61619	-1.61613	-1.61603	-1.61555	-1.61555	-1.61542	-1.61540	-1.61520	-1.61520	
0	-0.01413	-0.01416	-0.01415	-0.01418	-0.01421	-0.01421	-0.01332	-0.01334	-0.01329	-0.01332	-0.01327	-0.01332	
Span (mV/'V)	-4.00193	-4.00190	-4.00187	-4.00188	-4.00180	-4.00173	-4.00218	-4.00206	-4.00204	-4.00189	-4.00179	-4.00163	0.00014 mV/V
SHUNT CAL (mV/V)													-0.004 %
Raw zero	-0.01429	-0.01426	-0.01428	-0.01429	-0.01434	-0.01434	-0.01340	-0.01344	-0.01346	-0.01345	-0.01339	-0.01343	
Raw Neg SCAL	-0.99896	-0.99894	-0.99897	-0.99898	-0.99901	-0.99904	-0.99810	-0.99812	-0.99814	-0.99812	-0.99807	-0.99810	
Net Neg SCAL	-0.98467	-0.98468	-0.98469	-0.98469	-0.98467	-0.98470	-0.98470	-0.98468	-0.98468	-0.98467	-0.98468	-0.98467	0.00001 mV/V
% Dev from avg	-0.001	0.000	0.001	0.001	-0.001	0.002	0.002	0.000	0.000	-0.001	0.000	-0.001	-0.001 %
Raw zero	-0.01428	-0.01428	-0.01430	-0.01432	-0.01433	-0.01434	-0.01343	-0.01344	-0.01346	-0.01347	-0.01341	-0.01347	
Raw Pos SCAL	0.97123	0.97125	0.97123	0.97122	0.97118	0.97118	0.97210	0.97206	0.97207	0.97204	0.97210	0.97205	
Net Pos SCAL	0.98551	0.98553	0.98553	0.98554	0.98551	0.98552	0.98553	0.98550	0.98553	0.98551	0.98551	0.98552	0.00001 mV/V
% Dev from avg	-0.001	0.001	0.001	0.002	-0.001	0.000	0.001	-0.002	0.001	-0.001	-0.001	0.000	0.001 %