

# LOOKING UNDER THE BRIDGE

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*Abstract - A technique is presented for observing the individual contributions of each element within a transducer based on the Wheatstone bridge measurement circuit topology. An analog signal representing the appropriate sum of all the individual analog elements is simultaneously available. The approach involves opening any convenient corner of the bridge and observing the resulting series string of varying impedances by using the Anderson loop measurement circuit topology. This technique finds application in the development and testing of transducers and can also be used to cause each element within a transducer to have the designer's preferred influence on the output of the transducer.*

## INTRODUCTION

The measurement circuit topology of choice for observing small changes in variable-impedance transducer elements has long been the Wheatstone bridge. This topology presents a continuous differential signal that is a function of the various impedance levels and especially of the impedance variations in all four arms of the bridge circuit.

However, the bridge topology does not usually inform the observer what individual sensing elements are contributing to the overall differential output. Single-element impedance variations can be identified using the bridge topology only when it is arranged in advance that only one element in the bridge will vary, an awkward situation when attempting to identify what is really happening to each individual element of a transducer in operation. There is a need to somehow look “under the bridge” at each individual element of a Wheatstone bridge in normal transducer operation to understand the details of what is going on electrically in a transducer. Fortunately, a simple technique is available to accomplish these observations.

This paper explains a technique for looking “under” the Wheatstone bridge and discusses its capabilities and limitations as an electrical diagnostic technique for bridge transducers. The technique offers some unique advantages for operational signal conditioning as well.

It is possible to observe variations in individual sensing elements typically connected in a bridge circuit topology by “opening” the bridge to form a series circuit of the four variable impedances. Then dual-differential subtraction circuit functions can enable the variations in each individual element of what had been a bridge circuit to be simultaneously and continuously observed with respect to a single reference impedance with the same excitation current flowing through all of the impedances in series. Simultaneously, the continuous analog sum of the individual elements can be observed. This summed signal is quite similar to the usual output of a bridge circuit. The measurement circuit topology invented to accomplish this sort of observation has come to be known as an Anderson loop [1,2]. For simplicity, these topologies will usually be referred to as the “bridge” and the “loop.”

## DUAL-DIFFERENTIAL SUBTRACTION

This section summarizes an enabling technology for the simultaneous observation of impedance variations. The dual-differential subtractor (referred to as a “subtractor” for simplicity) enables many new measurement opportunities [3].

The dual-differential subtractor is a six-terminal, three-port active analog electronic circuit function defined in Fig. 1. The subtractor presents its analog output where it can be most usefully observed in the system. Subtractors typically deal with floating inputs and may provide either grounded or floating outputs.

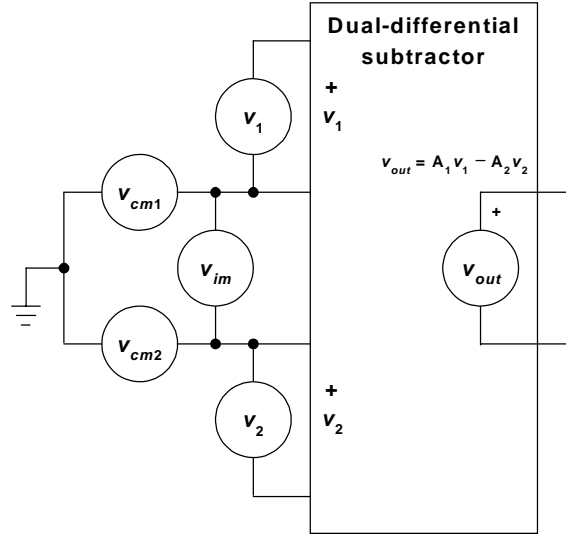


Figure 1, The dual-differential subtractor

The ideal dual-differential subtractor delivers at its output,  $v_{out}$ , the difference between two input potential differences,  $v_1$  and  $v_2$ , observed without energy transfer and amplified by gains  $A_1$  and  $A_2$ , respectively. The output is uninfluenced by any common mode potential difference,  $v_{cm1}$  and  $v_{cm2}$ , or interior mode potential difference from one input to the other,  $v_{im}$ .

The equation modeling the ideal dual-differential subtractor is:

$$v_{out} = A_1 v_1 - A_2 v_2 \quad (1)$$

Because  $A_1$  and  $A_2$  can assume the designer’s choice of values, the dual-differential subtraction function can vary the influence of  $v_1$  and  $v_2$  on the output.

The theory underlying the Anderson loop combines an active, dual-differential subtractor with Kelvin sensing of observed potential differences across two (or more) impedances carrying the same current [4]. The subtractor develops at its output port the difference between two selected (and possibly amplified) differential potential differences observed by its input ports. Different amplification factors can be used in observing the various loop potential differences and the loop can contain any practical number of observed impedances. The design of practical full- and half-subtractors is beyond the scope of this paper, but extensive information can be found in the references available for download [1-8].

The next section describes a test method using subtractors operating in an Anderson loop to continuously observe each individual sensing element impedance variation as well as their appropriate analog sum.

## TEST METHOD

The technique for looking “under the bridge” to see how each individual sensing element is varying requires that the basic bridge illustrated in Fig. 2 be opened and that three additional wires be added to the circuit as illustrated in Fig. 3. Any convenient corner of the bridge can be opened for this purpose unless the bridge transducer contains special elements that serve to compensate for temperature changes and adjust the initial offset of the transducer. The test engineer will need to determine which is the appropriate bridge corner to open.

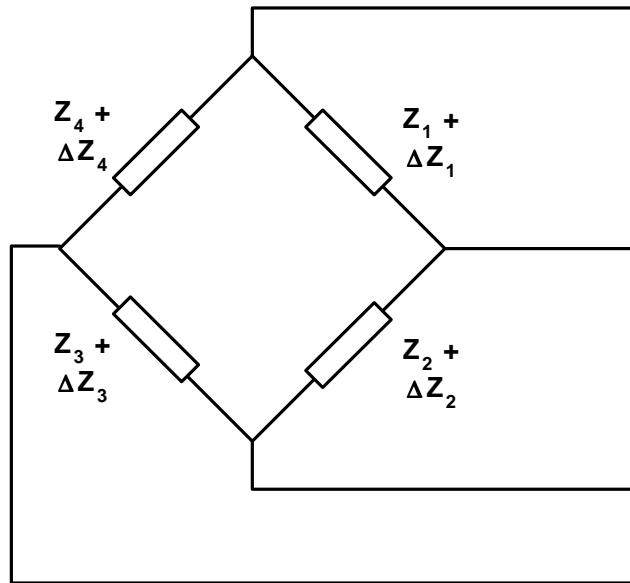


Figure 2, The typical Wheatstone bridge.

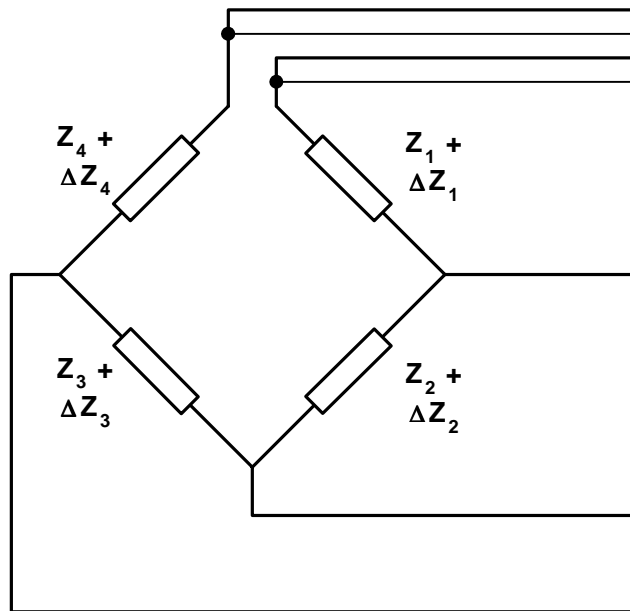


Figure 3, The bridge is opened and three additional wires are added.

After the three wires are added to yield the circuit illustrated in Fig. 3, the bridge schematic diagram can be rearranged to reflect the series topology illustrated in the left portion of Fig. 4. An additional impedance,  $Z_{ref}$  is added to the series

string of sensing elements in Fig. 5.  $Z_{ref}$  should be a very stable impedance with its impedance value selected as the nominal value of the individual bridge elements.

The excitation current,  $i_{exc}$ , can be set at half of the current normally used to excite the bridge. This excites the individual sensing elements at their normal current level so they experience their usual power dissipation.

Note that the sensing elements in Fig. 5 are observed in a Kelvin (remote-sensed) manner. Also note that the three middle sensing wires do double duty because the lower end potential of the sensing element above them and the upper end potential of the sensing element below them are the same potential.

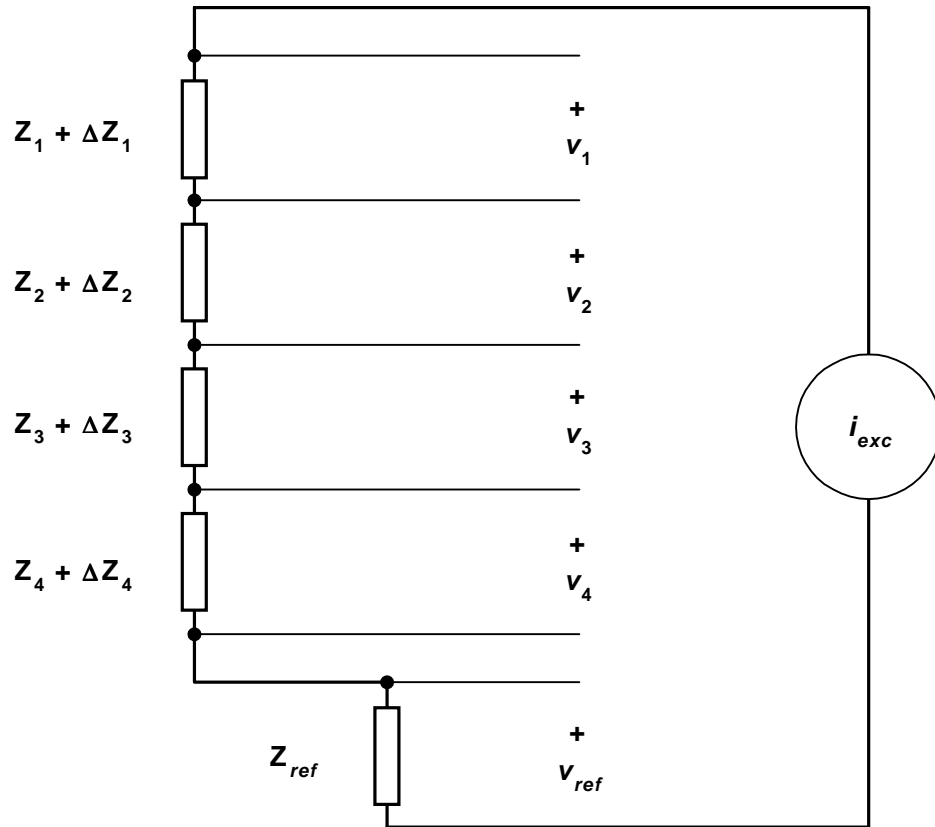


Figure 4, A reference impedance and current excitation source are added.

Referring to Fig. 5, a dual-differential subtractor circuit function (DDS1) is connected with its first differential input,  $v_1$ , monitoring the voltage drop across the first sensing element,  $v_1$ . Its second differential input,  $v_2$ , is connected to monitor the voltage drop across the reference impedance,  $v_{ref}$ . Similarly, three more subtractors (DDS2 through DDS4) are connected to monitor sensing impedance voltage drops  $v_2$ ,  $v_3$  and  $v_4$  with their first,  $v_1$ , input and  $v_{ref}$  is monitored by the subtractors' second,  $v_2$ , inputs connected in parallel. The equations modeling this example have the  $A_1$  and  $A_2$  amplification factors of the four subtractors set to unity.

Now consider what each of the four subtractor outputs in Fig. 5 will represent. For simplicity, let us assume that the initial impedance of each bridge element is the same and equal to  $Z$ . (Offset adjustments can be made in practical subtractors to cause this condition to appear to hold for the various sensing elements in the circuit.) When  $Z_{ref} = Z$ , the subtractor output voltages will be:

$$v_{out1} = i_{exc} \Delta Z_1 \quad (2)$$

$$v_{out2} = i_{exc} \Delta Z_2 \quad (3)$$

$$v_{out3} = i_{exc} \Delta Z_3 \quad (4)$$

$$v_{out4} = i_{exc} \Delta Z_4 \quad (5)$$

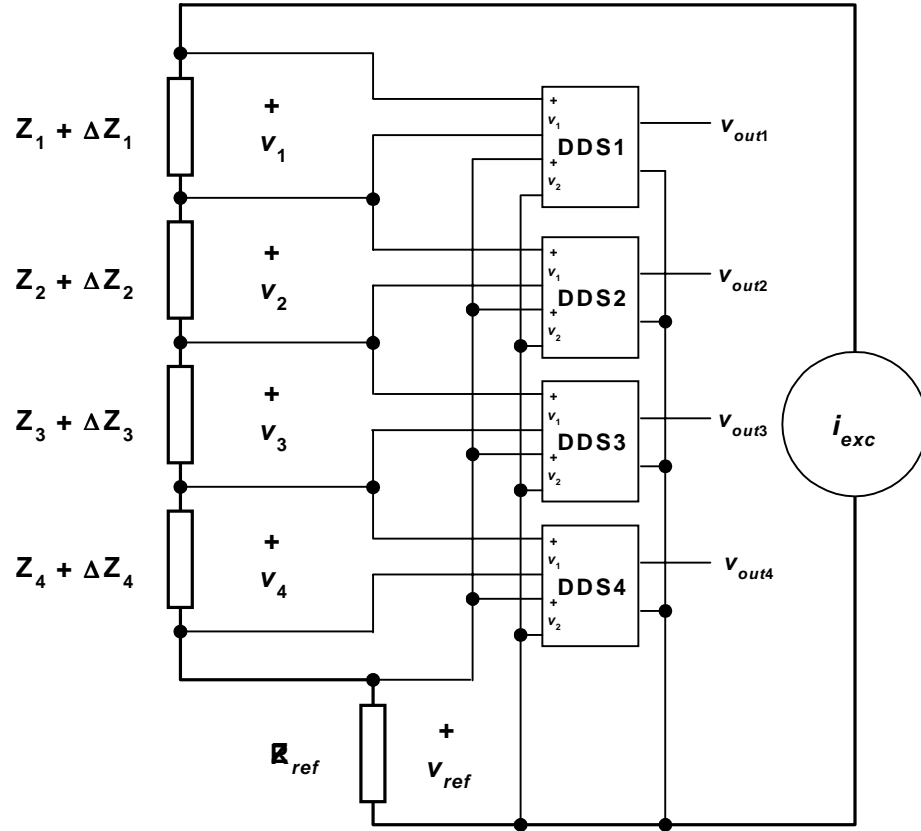


Figure 5, The Anderson loop method is used to observe the four sensing element outputs

Then the variations of each individual sensing element can be calculated by:

$$\Delta Z_1 = (v_1 - v_{ref}) / i_{exc} \quad (6)$$

$$\Delta Z_2 = (v_2 - v_{ref}) / i_{exc} \quad (7)$$

$$\Delta Z_3 = (v_3 - v_{ref}) / i_{exc} \quad (8)$$

$$\Delta Z_4 = (v_4 - v_{ref}) / i_{exc} \quad (9)$$

The loop current excitation level and the subtractor output voltage indicator sensitivity can be adjusted such that the readout represents the output engineering unit value of its respective sensing element. The linear  $y = mx + b$  function is commonly employed in real-time calculations for this purpose.

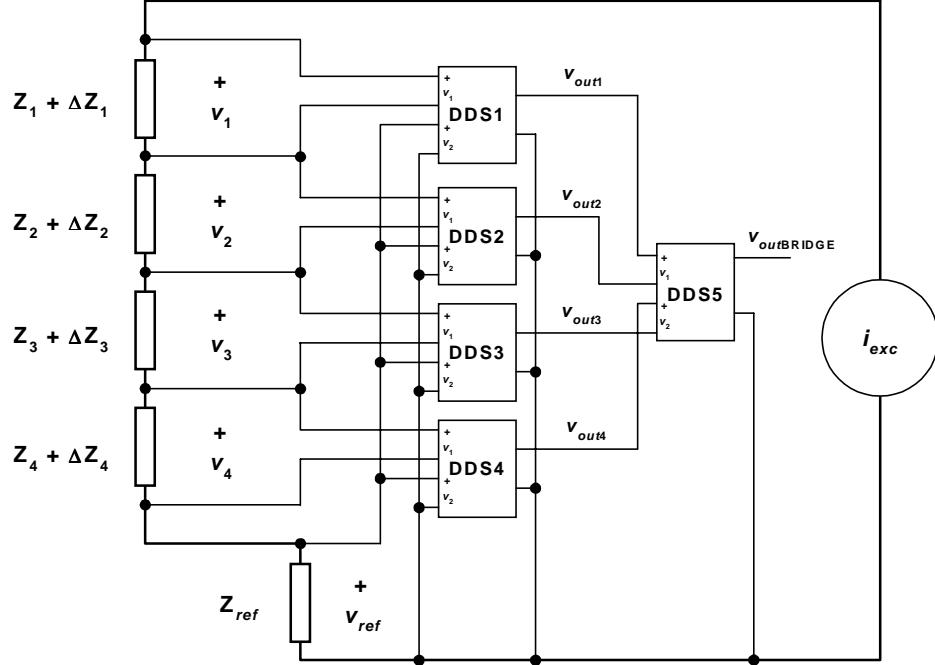


Figure 6, “Bridge” combination of subtractor outputs.

For convenience in digitizing the signals, the individual subtractor outputs,  $v_{out1}$  through  $v_{out4}$ , defined in Eq. 2 through 5 are often amplified and presented with respect to power common for convenient connection to a high-resolution analog to digital converter. The resulting digital data can be combined according to Eq. 10 to yield a result that is nearly equivalent to a Wheatstone bridge connection of the sensors,  $v_{outBRIDGE}$ . The two primary differences between the response of the Anderson loop and the Wheatstone bridge are (1) the loop measurement circuit topology response is completely linear for changes in individual sensing impedances while the bridge topology response is nonlinear and (2) the loop provides a 6dB voltage gain when compared to a bridge having the same power dissipation in each element of the bridge.

$$v_{outBRIDGE} = v_1 - v_2 + v_3 - v_4 = i_{exc} (\Delta Z_1 - \Delta Z_2 + \Delta Z_3 - \Delta Z_4) \quad (10)$$

The four subtractor outputs in Fig. 5 can be connected to the four input terminals of an additional dual-differential subtractor as illustrated in Fig. 6. This connection yields the analog sum,  $v_{outBRIDGE}$ , of the transducer element variations much like the signal developed from the bridge measurement circuit topology.

## OPERATIONAL POSSIBILITIES

It is reasonable to form an output from four (actually, for any number of) sensing elements that differs from the function illustrated in Eq. 10. A weighted combination can be developed either with analog circuitry or digitally from individual output changes. This approach can cause each element of a transducer to have whatever influence on the output the designer may choose. Transducers can be designed with either an even or an odd number of sensing elements when using the loop topology. This can make practical sensor designs that previously were unrealistic to develop.

## LIMITATIONS

The primary limitation of the Anderson loop, when compared to the Wheatstone bridge, is that it requires an active dual-differential subtractor circuit to accomplish the necessary subtraction. The Wheatstone bridge uses the arrangement of passive components to accomplish subtraction and thereby delivers a lower output voltage level and can have a lower noise floor. While practical subtractors often add almost imperceptibility to the noise level in real measurement situations, they do add some noise [5]. Other less significant limitations shared by both the bridge and loop circuits are discussed in the references.

## CONCLUSIONS

It is practical to make a simple wiring modification to most transducers wired in a Wheatstone bridge configuration that permits the observation of each individual sensing element's contribution to the transducer's output by reconnecting the sensing elements in an Anderson loop. This development gives the designer a powerful new testing technique for understanding the operation of a transducer and to enable unusual transducer designs.

## REFERENCES

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Most of the above references are available for download as pdf files through <http://www.vm-usa.com/links.html>