The Varley loop and Murray loop tests for fault location in telephone circuits

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ABSTRACT AND INTRODUCTION

Metallic ("copper") telephone lines are subject to many kinds of electrical faults. A conductor may come "open"; the two conductors of a pair may become "crossed" (short-circuited). One conductor of a pair may become "grounded", or may become crossed with a conductor of another pair.

For over 100 years before the availability of modern fault locating systems, ingenious schemes for locating the faults, based on specialized combinations of precise resistance measurements (typically made by special adaptations of the Wheatstone bridge), were in widespread use.

Important among these schemes was one called the "Varley loop", which actually refers to a family of closely-related measurement techniques. Another similar family of tests are called the "Murray loop" tests. This article describes these tests and the instruments by which they were traditionally made.

1 INTRODUCTION

Metallic ("copper") telephone lines are subject to many kinds of electrical faults. A conductor may come "open"; the two conductors of a pair may become "crossed" (short-circuited). One conductor of a pair may become "grounded", or may become crossed with a conductor of another pair.

In modern times, most such faults can be handily located, physically, by the use of time domain reflectometry (TDR), sometimes called "cable radar". Pulses are sent down the line, and will be (at least in part) reflected by the "characteristic impedance discontinuity" introduced by the fault. The time required for the pulse to return, compared against the time for the pulse to return from the distant end of the line (where there is placed an intentional discontinuity to provoke a reflection there), can give an accurate indication of the physical location of the fault.

But for over 100 years before the availability of TDR, telephone lines suffered such faults (perhaps even more frequently and mysteriously than today), and they too had to be physically located. Ingenious schemes for locating the faults, based on specialized combinations of precise resistance measurements (typically made by special adaptations of the Wheatstone bridge), were in widespread use.

Important among these schemes was one called the "Varley loop", which actually refers to a family of closely-related measurement techniques. Another similar family of tests are called the "Murray loop" tests. This article describes these tests and the instruments by which they were traditionally made.

2 ABOUT "CIRCUIT"

In this article, I will frequently refer to a pair of metallic conductors (these can be twisted pairs in a cable, or "mated" conductors in an open-wire line) as a "circuit", a term that I think will be readily appreciated by the reader. I need to point out, however, that this is not a precise use of the terminology of the telephone industry.

There, the term "circuit" means a communication path ready to be accessed by a manual switchboard or automatic switching system. If it is implemented "enroute" by a pair of conductors, the "circuit" consists of the pair plus such terminating equipment as might be needed at each end to interface with the switching system. The latter may include signaling circuitry and/or various transmission elements.

Then, the pair itself is usually referred to as a "facility".

But here, for ease of recognition by a range of readers, I will speak of the pair as a "circuit".

3 THE WHEATSTONE BRIDGE

3.1 Introduction

The "Varley loop" family of measurements are all specialized applications of the Wheatstone bridge, an instrument for making (usually quite precise) measurements of electrical resistance. It is important that the reader understand the principles of that instrument and some matters of the implementation of the varieties used in telephone work. This section will provide that background.

3.2 History

What we today speak of as the "Wheatstone bridge" was first described by the British physicist S. H. Christie in an 1833 paper on the electrical and magnetic properties of metals. Christie had devised the scheme as a tool in his research to precisely compare the resistance of various electrical conductors. But this paper did not serve to call general attention to the enormous potential of the scheme in the whole field of electrical measurement.

That was done in 1843 by famed British physicist Charles Wheatstone in a seminal paper on electrical measurements. Wheatstone's paper described various improvements in Christie's technique and illuminated its broader application to electrical measurement. Wheatstone gave full credit in his paper to Christie as the original inventor of the technique, but nevertheless Wheatstone's name became indelibly associated with it.

3.3 Principle

Figure 1 shows the circuit principle of the Wheatstone bridge.

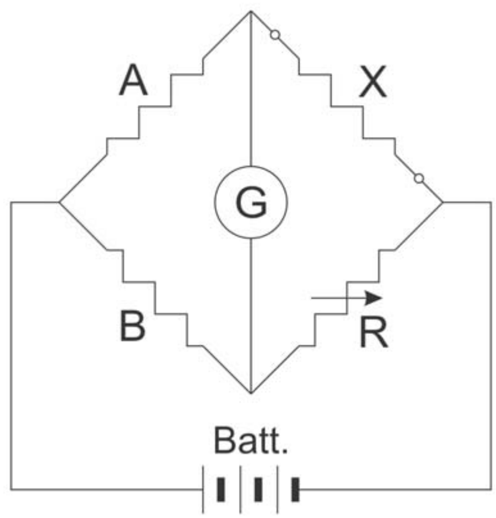

Figure 1. Wheatstone bridge–circuit principle

A and B are two "fixed" resistors (and the symbols A and B also represent their resistances). R is a variable resistor (and the symbol R also represents its resistance). Imagine that it has markings showing its resistance at any given setting. (More on the actual implementation of these elements shortly). X is the circuit element whose resistance is to be determined (and of course the symbol X also represents its resistance).

G is a very sensitive zero-center microammeter. For historical reasons It is referred to as a *galvanometer* (hence the symbol). Batt represents a battery (typically made of dry cells)–often with its voltage selectable over a range of perhaps 20-270 V, as needed for various situations).

In use, the operator varies resistor R until there is no current through the galvanometer (as evidenced by its pointer being at "zero"), the bridge then being said to be "balanced". This occurs when the following equation is satisfied:

$$\frac{A}{B} = \frac{X}{R} \tag{1}$$

which we can rewrite as:

$$X = \frac{A}{B} R \tag{2}$$

The operator reads the resistance of R and, from the equation just above (and knowing A and B, or at least A/B), calculates X.

3.4 Implementation of A and B

From equation 1 we can realize that, if the resistance of X is known to be rather high, or rather low, it will be advantageous to have A/B not be 1 but rather to be greater or less than 1. Accordingly, it is desirable that A and B can be changed to change the ratio A/B

In Wheatstone bridge instruments of the type used in telephone work, the sum of A and B is constant (1000 ohms in one typical instrument), and in fact A and B together are implemented as what is essentially a step potentiometer, as seen in figure 2.

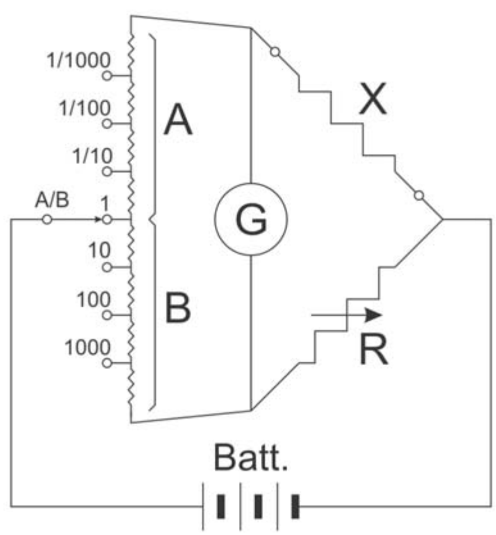

Figure 2. Implementation of A and B

There is a string of (precision) resistors in series, and a switch ("A/B" in the figure) connects to any one of the junctions between the resistors. Thus the string of resistors above the switch setting make up A, and the string of resistors below the switch setting make up B.

On the instrument panel, the positions of the knob of this switch[1] are labeled with the ratio A/B (given as a fraction). In one common model, the available ratios are:

1/1000 1/100 1/10 1 10 100 1000

(There some other ones too, for specialized situations. We will encounter some of them later.)

This notwithstanding, in the figures to follow I will show A and B in the traditional way.

3.5 Implementation of R

In Wheatstone bridge instruments of the type used in telephone work, R is implemented in the style of a “decade resistance box”. There are typically four switches, each of which can put into a series circuit (R) from 0 to 10 uniform “steps” of resistance. For the first switch, the step is 1 ohm; for the second switch, 10 ohms; for the third, 100 ohms; and for the fourth, 1000 ohms. Thus the resistance of the R branch of the bridge can be set from 0 through 9999 ohms, in 1-ohm steps.

The switches have robust contacts so as to avert any accidental introduction of unaccounted-for resistance in the R branch

3.6 Overall range

With R able to be varied from 0 through 9999 ohms, and A/B able to be varied from 1/1000 to 1000, with this instrument we should theoretically be able to measure resistances from 0.001 ohm though 9,999,000 ohms. In reality, this can’t really be done for very small resistances. because of the resistance of the circuit leads inside the instrument (and whatever external leads we need to connect to the element under test).[2] And various considerations mean that measurements in the upper reaches of this theoretical range can’t really be made, either.[3]

3.7 Galvanometer sensitivity

When we first “energize” the bridge, presumably it is not somehow accidentally in perfect balance, and is probably not even close. As a

[1] The switch itself may be labeled “A/R””, “ratio”, or “multiply by”.

[2] There are, however, specialized variants of the Wheatstone bridge that are capable of measuring very small resistances. These are outside the scope of this article.

[3] Clever ways of overcoming this are built into the most sophisticated instruments.

result the current through the galvanometer may be quite high. This will slam the galvanizer movement against one of its stops, quite possibly damaging the galvanometer.

A second issue if that, as we change R to seek balance, we might well pass through the balance point rapidly, the result being that the galvanometer needle will suddenly move from one end of its travel to the other. This situation can make setting R for exact balance quite "tricky".

To deal with both these situations, there is usually a set of push button switches that control the galvanometer's sensitivity by putting various resistances in series with it.[4] Typically the sensitivity settings will be 0.001[5], 0.01, 0.1, and 1 (the latter being "full sensitivity"). With no button pressed, the galvanometer is disconnected (a good state for it to be in when the bridge is first energized).

Thus, at the beginning of a "run", the operator might set A/B to 1 and R to 0, then press the 0.001 galvanometer sensitivity button. The galvanometer will certainly move in the "R is too small" direction but by a modest amount. The operator might the move the "1000 ohm" switch in the R set to 1 and see if the galvanometer reverses direction. If not, he may shift the A/B switch to 10, and then again move the "1000 ohm" switch in the R set to 1 and see if the galvanometer reverses direction, and so forth.[6]

As the operator sees that balance is being neared, he may push the 0.001 galvanometer sensitivity button, and then the 0.01 button, and then the 0.1 button, finally using the 1 button (full sensitivity) as balance is precisely attained.

3.8 Typical unit

Figure 3 shows a typical "portable" Wheatstone bridge of the general type often used for telephone work, made by the noted precision instrument manufacturer Leeds & Northrup.

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[4] Although of course the galvanometer actually responds to the current through it, we can also look at its role in the Wheatstone bridge as that of a voltmeter, and the addition of series resistance changes its sensitivity as a voltmeter.

[5] Not found on all instruments

[6] Technicians being trained in this work are taught a strategy of quickly finding balance that I never learned!

Figure 3. Leeds & Northrup portable Wheatstone bridge

In this unit, the four switches across the top are used to configure the instrument for various types of test. The A/B switch (“RATIO”) is at the upper left. The four dials on the right are the decade dials for setting R. The three galvanometer sensitivity switch buttons (three only on this instrument) are at the bottom. The galvanometer (here with a physical pointer) is at the lower left.

3.9 In test boards

The unit typically mounted at a test board is of a considerably different physical design, but essentially has the same repertoire of controls. There the galvanometer is usually of the “reflection” type, having in effect a very long pointer (made of a light beam) to enhance its sensitivity and reduce its inertia.

3.10 An example test setup

Figure 4 shows the setup for an important use of the Wheatstone bridge in telephone work, determining the loop resistance of a telephone circuit. The two conductors of the circuit are connected together (“shorted”) at the far end for the test, and the two conductors at the “measuring” end are connected to the bridge as shown.

The figure is drawn to emphasize the relationship to the "theoretical" Wheatstone bridge circuit seen earlier.

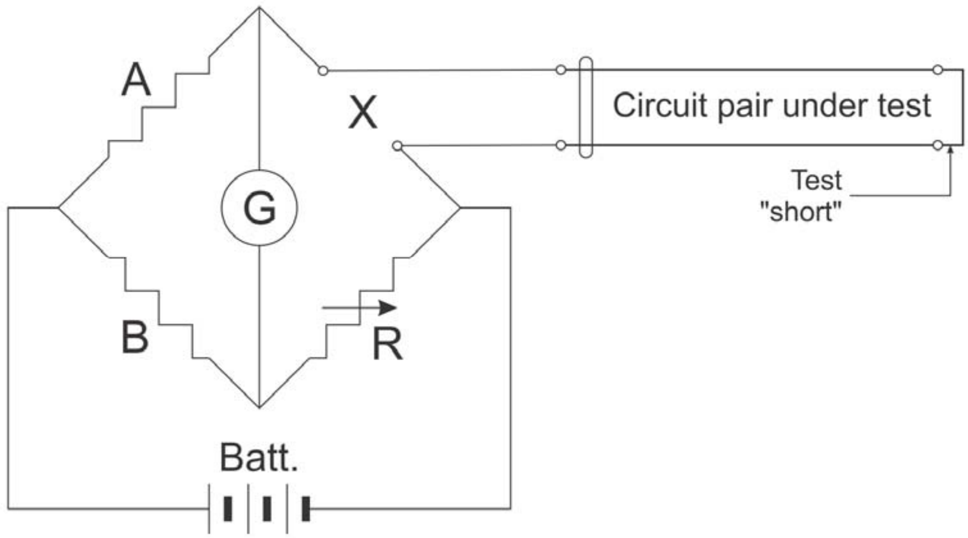

Figure 4. Measuring loop resistance of a circuit

The technician adjusts the bridge until balance is attained. Then the loop resistance of the circuit is determined from the bridge settings as:

$$\text{loop resistance} = \frac{A}{B} R \qquad (3)$$

Now I will introduce a "clinker": the circuit under test has a (single) fault, one conductor having somehow become grounded at a certain point. We see the situation then in figure 5.

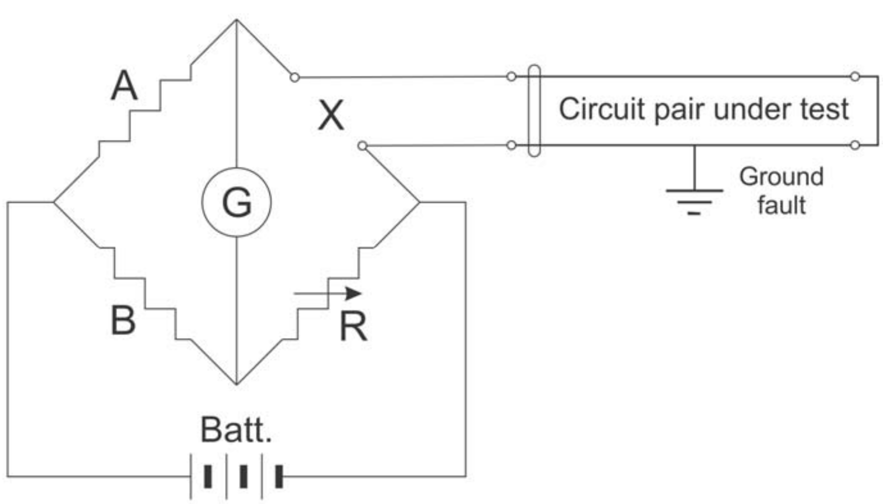

Figure 5. Ground on the circuit

The battery in the Wheatstone bridge is itself "floating" (that is, neither side is connected to ground), and thus the bridge itself is "floating". As a consequence, no current flows through the ground fault, and thus it does not in any way disrupt the bridge in making its determination of the loop resistance of the circuit under test.

4 THE VARLEY LOOP TEST

4.1 Introduction

"Varley loop" actually refers to a family of closely related test schemes used to locate ground and cross faults in telephone circuits by the making of one or more resistance measurements, using a specialized adaptation of the Wheatstone bridge. Which test we use depends on the context.

I am not certain which "Varley" is honored by the name of this test.

4.2 Notation

In the discussion to follow, we will often be concerned with two different kinds of resistance:

- Conductor resistance. This is the resistance of a single conductor of a telephone circuit, perhaps over the entire length of the circuit or perhaps over only a certain portion of its length.

- Loop resistance. This is the joint resistance of the two conductors of a telephone circuit, perhaps over the entire length of the circuit or perhaps over only a certain portion of its length.

Since "R" is traditionally used for the adjustable arm resistance of a Wheatstone bridge, I will use "r" for these various resistances. For loop resistance. I will use an "L" subscript; designations without that should be recognized as conductor resistances.

Various (further) subscripts and numerical suffixes will be used to identify the specific resistances in the ensuing discussions These will be described as the need for them arises.

4.3 Our usual real objective

Various of the Varley tests give a result that is the loop resistance, or a conductor resistance, from one end of the circuit or the other to the location of the fault. But in most cases, our real quest is to learn the physical location of the fault, in order that we can go to that place and look for the cause of the fault. Accordingly, I will emphasize the equations that go directly to that result.

4.4 Speaking of equations

In the discussion of the first, simplest type of Varley loop measurements, I will derive the equation that gives the result. This is fairly concise.

But in the more complicated versions, although the derivation of the equations does not involve any advanced mathematics, it does require the quite tedious use of basic algebra. For the most part, I will spare the reader these exercises, rather proceeding, by implicitly asserting "it can be shown", directly to the equations used in actual measurement work,

4.5 The "simplified grounded Varley loop" test

This test can be used to locate a fault to ground if:

- We know accurately the loop resistance of the afflicted circuit between the two "end stations". (And that means "at the temperature at the time of the measurement".)
- The resistance per unit distance is constant for the entire length of the circuit (and that includes ruling out the possibility that, at the time of measurement, the temperature of the conductors is substantially between portions of the circuit).
- We know or can reasonably assume that the resistance of the two conductors of the circuit is the same (usually true, fortunately).

The setup is seen in figure 6. From here on I use a more direct layout of the leads for clarity.

$r1_N$ is the conductor resistance of the upper conductor of the pair ("!") from the bridge to the location of the fault ("N" for "near"). $r2_N$ is the conductor resistance of the lower conductor ("2") from the bridge to the location of the fault. r_{Lf} is the **loop resistance** from the location of the fault to the far end of the circuit ("F" for "far").

Note the round-end rectangle symbol telling us that the two conductors are a "pair" (and thus can reasonably be assumed to have the same resistance, overall or for any given portion).

For this test, we must set $A/B=1$ (so that $A=B$).

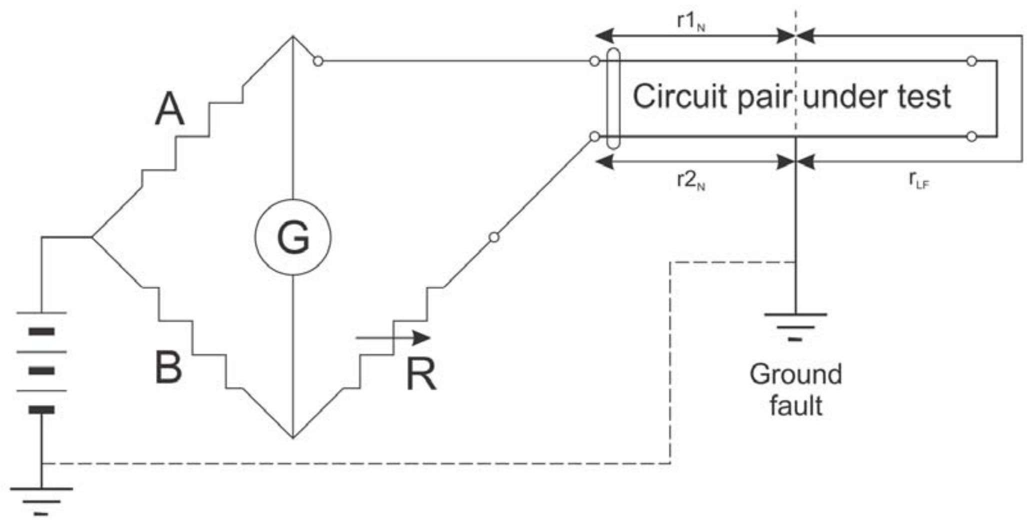

Figure 6. Basic Varley loop test

We balance the bridge.

The branch of the bridge that is usually called X comprises here the sum of $r1_N$ and r_{LF}. The branch of the bridge that is usually R comprises here R plus $r2_N$. And we have assumed that $r1_N$ will be the same as $r2_N$. I will thus call both their values just r_N.

Then the equation for balance will be:

$$\frac{A}{B} = \frac{r_{LF} + r_N}{R + r_N} \qquad (4)$$

But because A = B (as I said it must be for this test), A/B = 1, thus:

$$r_{LF} + r_N = R + r_N \qquad (5)$$

But the two appearances of r_N cancel out, leaving us with just:

$$r_{LF} = R \qquad (6)$$

How lovely! The loop resistance from the fault to the far end of the circuit is given directly by the setting of R.

Now, if we know the total physical length of the circuit (L) and its overall loop resistance P_T, we can readily determine the physical distance between the fault and the far end of the circuit this way:

$$D = \frac{r_{LT} - r_{LF}}{r_{LT}} L \qquad (7)$$

Note that if, because of the resistances involved, we cannot get a nice balance with A/B = 1, we are out of luck with this simple test.

4.6 The resistance of the ground fault

Often a ground fault is not a “dead short” to ground. But the (unknown) resistance in the ground fault path does not enter into the determination made by the bridge. As we see in figure 6, that resistance just ends up in series with the battery circuit, and thus affects the battery circuit current. But the value of the battery circuit current does not enter into the determination made by the bridge (so long as it is sufficient to give the needed sensitivity of balance).

The fault resistance can only be a problem if it is quite large, such that the battery current is reduced to the extent that the sensitivity of the bridge is too greatly degraded.

4.7 Ground potential differences

Neither does a difference in the DC ground potential between the fault and the bridge affect the determination made by the bridge. As we can see in figure 6, this would just add to or subtract from the bridge battery voltage. Of course, if the resulting net battery voltage is reduced to too small a value, the operation of the bridge may be too greatly degraded.

4.8 The “regular grounded Varley loop” test

But perhaps we do not know the resistance of the circuit (at least we may not know its resistance at the temperature existing when we test).

The solution is to first measure the loop resistance of the circuit (“now”) using the Wheatstone bridge. I will call that P_T (T for “total”).

Having done that, we could proceed as described above in section 4.8.

But it turns out that, apparently, it is sometimes desired to determine the resistance of the faulted conductor from the test station (what I call $r2_N$).

To get that, we again balance the bridge with the setup in figure 6. But this time we are free to set the A/B ratio as best supports getting an accurate balance with the resistances involved.

Then, the resistance of the faulted conductor from the test station to the fault is given by:

$$r2_N = \frac{Br_{LT} - AR}{A+B} \qquad (8)$$

But the bridge is not set to values of A and B, only A/B. We can recast equation 8 in terms of A/B, thus:

$$r2_N = \frac{P_T}{1+\frac{A}{B}} - \frac{R}{1+\frac{B}{A}} \qquad (9)$$

where of course B/A is the inverse of A/B.

This is not a very handy calculation.

4.9 The "check test"

After the technician has made a determination of the resistance of the faulted conductor from the near end to the fault (per figure 6), he may wish to confirm that result by making the test in an alternate way, which should yield exactly the same result. The connections for this "check test" are shown in figure 7.

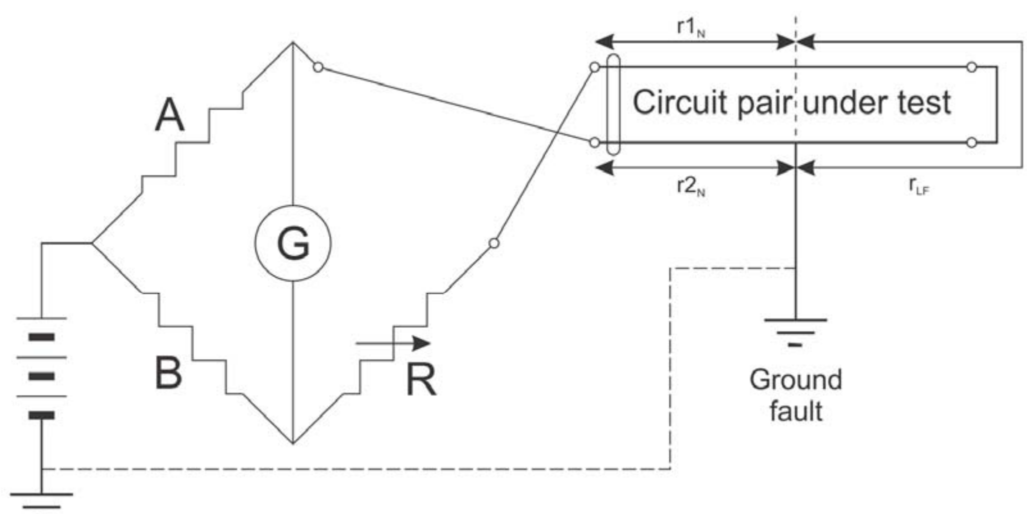

Figure 7. Varley check test

The two conductors of the circuit have just been "turned over" compared to the first test (*cf*. figure 6).

Here, the equation for determining the resistance of the faulted conductor to the fault, $r2_N$, is given by:

$$r2_N = \frac{A}{A+B}(R + r_{LT}) \qquad (10)$$

If all has gone well, the value of $r2_N$ measured this way will be identical to the value of $r2_N$ measured before.

Again we note that the bridge is not actually set for A/(A+B), only A/R (but see below). Putting that aside for the moment, depending on the range of the resistances involved, it will often be handy to have A/(A+B) be greater than the obvious value of 1/2 (when A=B). In fact for the resistances often encountered, a value of 10 would be handy.

Well, the Wheatstone bridges used in telephone work generally have, on their A/B dial, a setting of 1/9 (not shown on figure 2 as it would have seemed strange there). That leads to the handy value of A/(A+B) of 1/10. How nice.[7] And so we can actually use equation 10 very readily.

4.10 So, given all that

Given all that, if we wish to know the resistance of the faulted conductor from the test station to the fault, and only do one test (not a second one to "check" the results of the first one), it would seem that the calculations would be easier if we used the "check" test rather than the "regular" test according to figure 6 and equation 9.

4.11 The normal-reversed test

A handwritten note from 1953 in an AT&T textbook presented this equation:

$$V = \frac{A}{A+B}(R_1 - R_2) \qquad (11)$$

where R_1 and R_2 were identified in the note as the bridge "R" settings at balance for two tests, one with the pair under test "normal" and one with it "reversed", and V was described as "the correct value of the Varley".[8]

This test procedure had an eerie similarity to the matter of the "Varley check test" described in section 4.9 where, having made a basic grounded Varley test to determine the resistance to a ground fault, the

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[7] There is often also a setting for A/B of 4, leading to A/(A+B) being 5, also a handy value for making calculations.

[8] In that textbook, "V" with subscripts 1, 2, and 3 was used for the value of R at balance for the three tests in the 3-Varley test suite (the order of 1, 2, and 3 being opposite to the order of my subscripts a, b, and c and the order of 1, 2, and 3 as found in the actual procedure documents.).

conductors of the circuit under test were reversed and the bridge balanced again to give a "check" on the first result (a different equation being used that for the first test).

I did the algebra to ascertain whether equation 11 actually gave some circuit value of interest. I was pleasantly surprised to learn that:

$$r_{LT} = \frac{A}{A+B}(R_1 - R_2) \qquad (12)$$

where r_{LT} is the loop resistance of the entire circuit.

It is not clear why one would want to determine the loop resistance of a pair this way (rather than, for example, using the test shown in figure 4), and at present we do not know in what context the author of that note was operating. But it was a fascinating episode. It in fact spawned my review of the Varley loop tests that led to this article.

It is interesting to note here the appearance of the scaling factor A/(A+B), which we earlier encountered, and will encounter again in later parts of this article.

4.12 The "3 Varley test"

Sometimes we cannot use the "mate" to the afflicted conductor as a player in this drama (perhaps it has some different kind of fault). In that situation, and various other situations, the "3 Varley test" is used.

As we might guess, this involves setting up the test in three different ways and balancing the bridge in each. Then, from a simple equation, we can easily calculate the distance from the test station to the fault as a fraction of the known physical length of the circuit.

I will call the three tests "test 1", "test 2", and "test 3"[9].

The test suite requires, in addition to the faulted conductor, two other "good" conductors. One of these can be the mate to the faulted conductor, but it need not be. It is not necessary that either of the two "good" conductors can be assumed to have the same resistance as the faulted conductor.

Here again we are free to set A/B as best facilitates getting an accurate balance with the resistances involved. The A/B setting, however, must be the same for all three tests of the series.

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[9] This is the notation used in all the referenced documents to which I refer.

Figure 8 shows the connections for test 1.

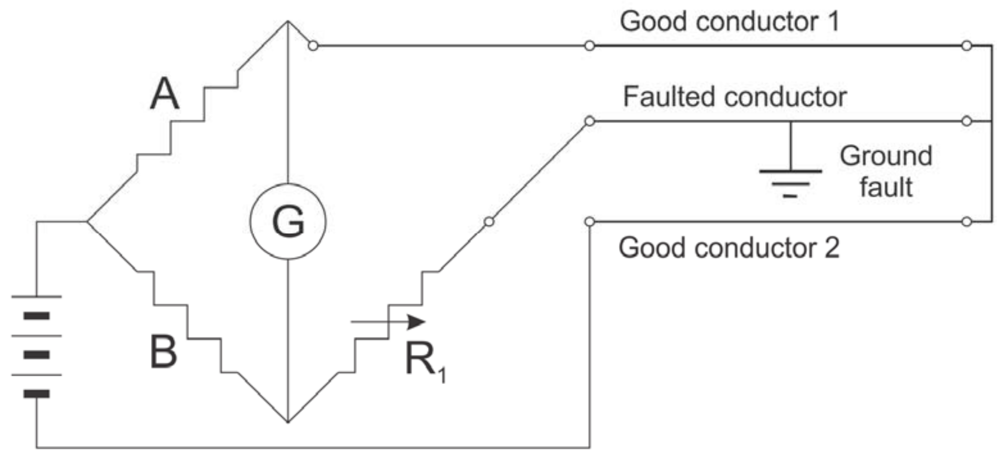

Figure 8. 3 Varley test 1

The bridge is balanced in the usual way. I will call the value of R at balance "R_1".

Figure 9 shows the connections for test 2.

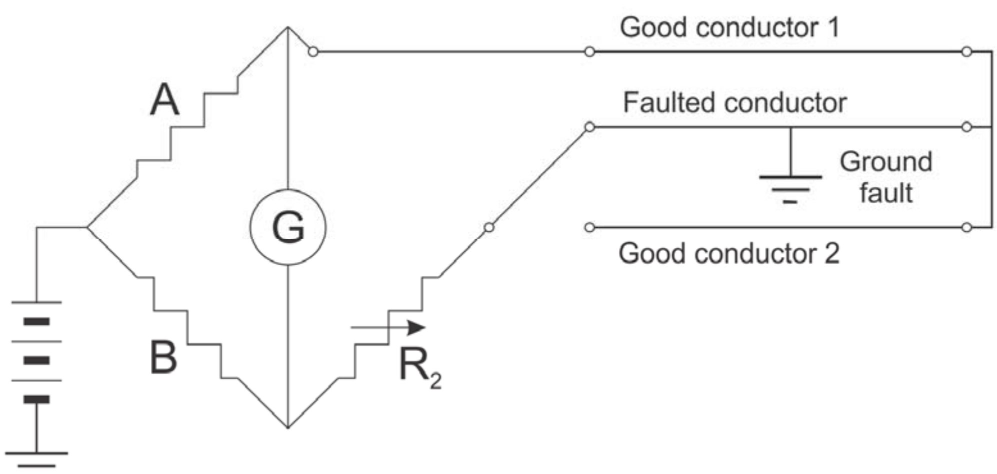

Figure 9. 3 Varley test 2

The bridge is balanced in the usual way. I will call the value of R at balance "R_2".

Figure 10 shows the connections for test 3.

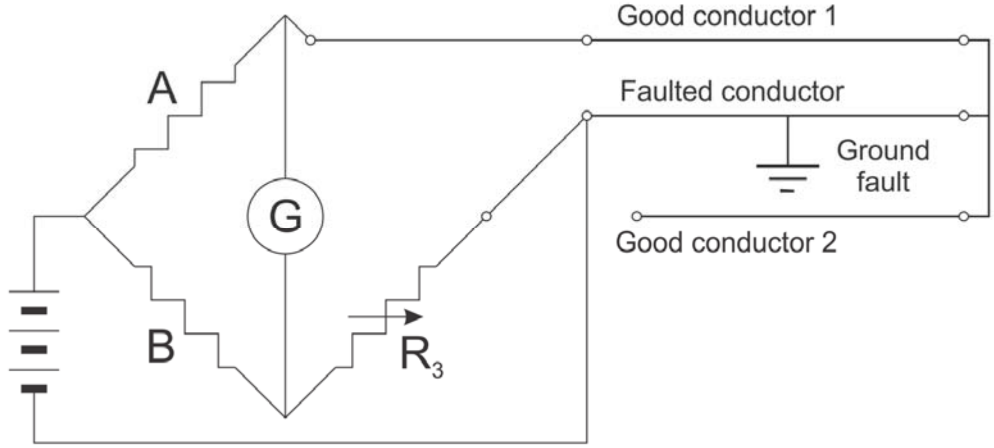

Figure 10. 3 Varley test 3

The bridge is balanced in the usual way. I will call the value of R at balance "R_3".

Now, with R_1, R_2, and R_3 in hand, we are able to calculate various things. I said earlier that often our real need is to reckon the physical distance to the fault, let's assume from the testing end of the circuit. This, which I will call D_N ("N" again for "near") is given by:

$$D_N = \frac{R_3 - R_2}{R_3 - R_1} L \qquad (13)$$

where L is the total physical length of the circuit.

But if we are interested in various resistances, we can proceed this way. The total resistance of the afflicted conductor, r_T, is given by:

$$r_T = \frac{A}{A+B}(R_3 - R_1) \qquad (14)$$

The resistance of the afflicted conductor from the testing station to the fault, r_N, is given by:

$$r_N = \frac{A}{A+B}(R_3 - R_2) \qquad (15)$$

The resistance of the afflicted conductor from the fault to the far end, C_F, is given by:

$$r_F = \frac{A}{A+B}(R_B - R_A) \qquad (16)$$

Note the recurrence here of the scaling factor A/(A+B). It is very handy if this has a value such as 1/10. To cater to this, as I noted earlier, the Wheatstone bridges used for telephone work usually have an A/B setting of 1/9, That leads to an A/(A+B) of 1/10.

The "good conductors" are just laborers in this drama. We said we need not be concerned with their resistances, and accordingly, I do not show the equations for their determination.

4.13 Locating a cross

In figure 5, we saw that the simplified Varley loop test could be used to locate a cross, rather than a ground, by a very simple circuit rearrangement. Although I did not show it, the same is applicable to the regular Varley loop test.

In conceptually the same way, the 3 Varley test can also be adapted to locate a cross rather than a ground, I do not show the arrangements here as the drawing gets a bit cluttered.

4.14 Test lead resistance

In actual practice, the physical length of a pair and its normal resistance are reckoned between the "demarcations" at which the pair is terminated at the central offices at both ends. The figures above suggest that the Wheatstone bridge is connected to the conductors at that demarcation.

But the reality may be much different. The primary test board, where the Wheatstone bridge is typically located, may, in a large central office building, be located some considerable distance from that pair demarcation. The leads connecting the circuits to that test board can have considerable resistance.

If we are just using the Wheatstone bridge to determine the loop resistance of a circuit, we can of course just subtract from the reading of the bridge the known resistance of the test lead pair.

But in the 3 Varley test scheme, it does not work out that simply. However, a simple change in the wiring arrangements results in the one test lead resistance that is troublesome being "canceled out".

In figure 11, we explicitly show, for the Varley C test, the test leads (with their resistances), and that special wiring. (It only affects the test C circuit.) We see that there is now an added test lead from the Wheatstone bridge[10] to the faulted conductor at the demarcation.

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[10] I have no idea how this is actually implemented in practice.

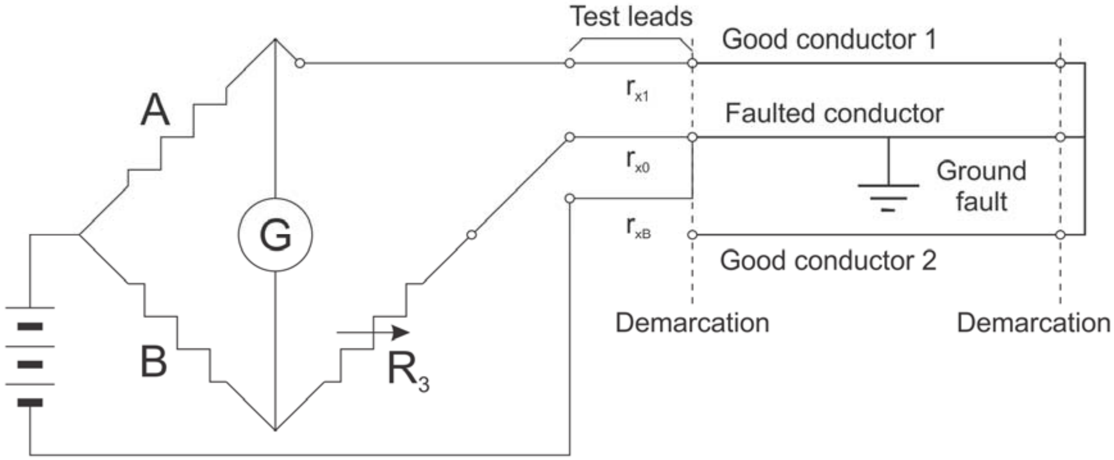

Figure 11. Varley 3 test 3 wiring to compensate for test lead resistance

If we go through the algebra for the entire 3 Varley test process in light of this arrangement (I will spare the reader this agony), we find that the value of r_{x0} (the resistance of the primary test lead to the faulted conductor) does not appear in any of the equations for the three resistance results (nor for the distance to the fault).

We know that the resistance r_{x1} (the resistance of the test lead to good conductor 1) is of no consequence since it, like the resistance of good conductor 1 itself, also cancels out in the results.

We know that the resistance r_{xB} (the resistance of the secondary test lead to the faulted conductor) is of no consequence since is it just in series with the battery (and we earlier noted that this resistance would not affect the bridge results).

Thus this setup avoids any effect on the result of even substantial resistance of the test leads.

5 THE MURRAY LOOP TEST

Closely to the Varley loop series of tests, and often also provided for by the Wheatstone bridge instruments used for telephone work, is another family of tests called the "Murray loop" tests. This is said to be especially useful for tests on shorter circuits (such as those often encountered on interoffice trunks in metropolitan areas).

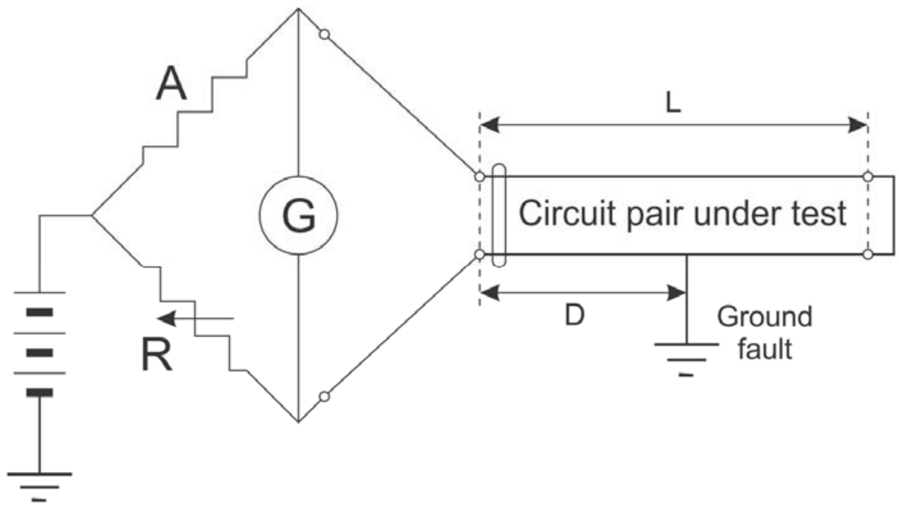

Figure 12. Murray loop test

The basic circuit arrangement is shown in figure 12. A switch on the Wheatstone bridge rearranges the circuitry to that shown for this test.

L is the physical length of the pair, and D is the physical distance from the test station to the fault (which is the result we want). We assume that the conductor resistance per unit length is uniform, and thus we can replace ratios of resistances with the ratios of the corresponding distances. Doing just that, we redraw the circuit to show the Wheatstone bridge in its classical form:

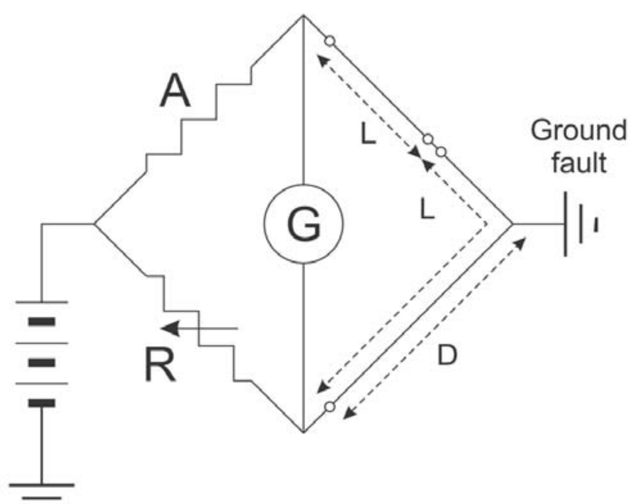

Figure 13. Murray loop test

Then, by inspection, we can write:

$$\frac{R}{A+R}=\frac{D}{2L} \tag{17}$$

and solving that for D gives:

$$D=\frac{R}{A+R}2L \tag{18}$$

The Wheatstone bridge instruments commonly used for telephone work facilitate use for this test by including, in the settings of the A/B dial, positions for A = 10, A = 100, and A = 1000 (typically labeled M10, M100, and M1000, the "M" of course being for "Murray"). It does not matter what the matching "B" resistance is, as the "B" resistor path is not in the circuit when the bridge is configured for the Murray loop test).

6 FURTHER ELABORATIONS

In order to deal with specialized fault location needs, many further elaborations of the basic Varley loop concept have been devised, some involving tests made from both ends of the circuit, and most involving very complicated calculations to get the desired result. These are all beyond the scope of this article.

7 REFERENCE SOURCES

In preparing for this article, I would like to have referred to the sections of the Bell System Practices covering these test schemes, but, although I could identify the sections I wanted, I was unable to find any of them on the Internet.

I did refer to these three publications:

- *Principles of Electricity and Magnetism as Applied to Telephone and Telegraph Work,* 1953 Edition, American Telephone and Telegraph Company, January, 1953.

- Technical Manual TM 11-372-6, *Telephone–Cable Splicing: Cable Testing*, Department of the Army, September, 1967. This indicates that it has largely been drawn from numerous sections of the Bell System Practices.

- National Guard Bureau Manual NGB 187, *Training Project for Repeaterman, Telephone (SSN 187)*, National Guard Bureau, June, 1950, largely a compendium of Air Force training monographs.

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