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RESEARCH REPORT

THE INDUCTIVE LOOP VEHICLE DETECTOR INSTALLATION ACCEPTANCE CRITERIA AND MAINTENANCE TECHNIQUES

Presented at the 55th Annual Meeting
of the Transportation Research Board
January 1976

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY

THE INDUCTIVE LOOP VEHICLE DETECTOR:

INSTALLATION ACCEPTANCE CRITERIA AND MAINTENANCE TECHNIQUES

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Prepared for Presentation at the Annual Meeting
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Washington, D. C.

January, 1976

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ABSTRACT

"The Inductive Loop Vehicle Detector: Installation Acceptance Criteria and Maintenance Techniques".

This paper describes techniques to improve the operation and reliability of Inductive Loop Vehicle Detectors. Three aspects are discussed: Installation design aids, installation acceptance criteria and maintenance techniques. The paper is divided into two sections, the first titled "To the Traffic Engineer" and the second "To the Maintenance Technician". The emphasis is on practical solutions to design, installation and maintenance problems. Technical data is provided, based on measurements of test loops located at the California Transportation Laboratory's Detector test site. All loops tested were six foot "square" loops consisting of three turns of twelve gauge solid wire using State of California Standard Specification Loop Lead-In Cable Type A (Sec. 86-5.01A(4); IMSA Specification: 19-1).

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INTRODUCTION

When the project that led to this document was undertaken it became obvious to this author that the field of vehicle detection was fraught with many maintenance frustrations and design pitfalls. Engineers and technicians alike hated vehicle detectors because they were unreliable, did not do the job for which they were intended, and sometimes never worked from the time they were installed. This paper represents only one step in the direction the author feels may relieve the pressures brought to bear on you, the technician and you the traffic engineer. The emphasis is in three parts: One, to enable the traffic engineer to predict, during the design phase, the inductance and sensitivity of his loop-leadin systems, thereby to predict whether the system will work with available loop detector amplifiers; two, to give those responsible for accepting a new installation a more exact method of evaluating a loop-leadin system before the loop detector amplifier is ever attached to the system; and three, to give the signal technician an effective means of isolating failures to the loop, leadin, or amplifier portion of the system.

TO THE TRAFFIC ENGINEER

INSTALLATION DESIGN CRITERIA

Statement of Premise: For loop-leadin systems where it is critical, the sensitivity may be calculated during the design phase, to verify

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that the loop-leadin system will function with available amplifiers.

Procedure: The percent change in inductance for the worst case vehicle will be calculated for the system in question. This will be compared to the sensitivity threshold of the amplifier selected (if the amplifier has not been selected, all brands which may be selected should be considered).

Example: Using Table 1 and Figures 1 through 3, the percent change in inductance (%ΔL) due to a Honda 100 motorcycle passing over the center of a 4-6x6 series-parallel connected loop system with 600 feet of leadin is calculated. The loop is installed within 1-inch of the surface of the road. From Table 1 the %ΔL for the 4-6x6 series-parallel connected loop is .06% and the loop inductance is 80 micro-henries. From Figure 2 the leadin inductance is about 130 micro-henries.

Using Formula 2 from Table 1

$$\%\Delta L_{\text{(Loop and Leadin)}} = .06 \times \frac{80}{80+130}$$

$$\%\Delta L_{L+l} = .023$$

Since the loop has been installed within 1-inch of the road surface, no reduction in sensitivity need be accounted for. Since the loop amplifiers purchased in this jurisdiction (State of California) are tested for a .03%ΔL high sensitivity threshold, the .023%ΔL

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may well not result in an output from Brand X or Y amplifier. Brand Z may advertise a high sensitivity threshold of .02% or less, so it may work, but a better approach might be to split the four loops into two sets of two, and provide a second leadin and amplifier. Using the same tables and procedures, the %ΔL for each of the two systems (2-6x6 series connected loops with 500 feet of leadin) is found to be .046%. This is a comfortable margin of sensitivity.

But suppose the original configuration was selected, and an amplifier with a .02%ΔL threshold was specified. And suppose a 3-inch layer of asphalt will be laid over the loop. From the graph, Figure 3, a reduction in sensitivity of almost 20% will result. Hence the %ΔL from the original calculation (.023%) will be reduced by 20% or .8 x .023 = .0184 %ΔL. Now the %ΔL due to the Honda 100 motorcycle is .018 which is .002 less than the threshold of the amplifier specified. Again the most reliable solution would be to split the 4 loop system into two, two loop systems resulting in a sensitivity of .037 %ΔL for each system. This allows a margin of safety should another layer of material be applied to the road surface at a later date. A good sensitivity margin, for design purposes, might be 30%. This would allow for an additional 5-inches of material to be added to the surface at a later date.

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INSTALLATION ACCEPTANCE CRITERIA

Introduction: Since it was not practical for every jurisdiction to use the same vehicle as a standard for the acceptance of new loop detector installations, it seemed desirable to choose a device which might closely model a vehicle, which might be easily fabricated, and which would be convenient to carry. Such a device might well model the worst case vehicle i.e., that vehicle most difficult for the system to detect. One such device is shown in Figure 4. While this device may well be used to test the operation of a loop detector system (system equals loop + leadin + amplifier) it may be more desirable to test the sensitivity of the loop-leadin portion of the system separate from the amplifier. A second device is required, one which will measure the loop-leadin's sensitivity to the vehicle model. This device when attached to the loop-leadin would measure the percent change in inductance (%ΔL) due to the presence of the vehicle model. Such a device is built by the Indicator Controls Corporation in Gardena, California (ICC Digital Loop Tester Part Number 3050). This device and its operation is described in the Section titled "To the Maintenance Technician".

Statement of Premise: Installation Acceptance testing, while including the measurement of loop resistance, insulation resistance and inductance, should also include a test for the loop-leadin system's sensitivity to a "standard" vehicle or vehicle model.

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Procedure: With the loop detector amplifier disconnected, the test device (if equipped with a standard amplifier connector) may be plugged directly into the harness. If the inductance change measuring device is the type described in Section 4 (loop oscillator-frequency counter type) the frequency of oscillation (f_1) is recorded. With the vehicle model placed in the center ($\pm$ 6-inches) of the loop the new frequency (f_2) is recorded. The percent change in frequency is then calculated according to the formula $(f_2-f_1)/f_1 \times 100$. It can be shown that the percent change in inductance is approximately equal to 2 times the percent change in frequency. This is a good approximation for ΔL up to 10%, and for loops where Q is greater than 5. The $\%\Delta L$ is then calculated by multiplying the above results by 2. The result is then compared with Table 1.

Example: A new detector installation, consisting of 4-6x6 series-parallel connected 3 turn loops and 250 feet of leadin is being tested for acceptance. The following measurements are taken:

1. Frequency of loop oscillator with no vehicle on any loop: $f_1 = 57994\ H_z$

2. Frequency of loop oscillator with vehicle model in center of loop: $f_2 = 58005$

The $\%\Delta L$ is calculated:

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$$\frac{f_2 - f_1}{f_1} \times 100 = \frac{11}{57994} = .019\% \quad \Delta f$$

Then

$$\%\Delta L = 2 \times \%\Delta f = 2 \times .019\% = \underline{\underline{.038\%\Delta L}}$$

Table 1 predicts the following: for a 4-6x6 series-parallel loop $\%\Delta L = .06$. The reduction due to 250 feet of leadin is calculated according to formula 2 of Table 1:

$$\%\ L_{L+l} = \%\Delta L \times \frac{L}{L+l} = .06 \times \frac{80}{80 + 55} = .036\%\Delta L$$

the leadin inductance l was determined from the graph Figure 2. The measured value is 5% higher than the table predicted; this loop's sensitivity is acceptable. Even if the measured value was 15% low the loop should be accepted however, because of the inherent inaccuracies of the test device and the values in the table.

MAINTENANCE TECHNIQUES

Statement of Premise: The loop-oscillator, frequency counter type test device will enhance maintenance capability.

Description of Section 4, "To the Maintenance Technician": Section 4 of this paper describes a loop-oscillator, frequency counter test

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device, and gives procedures and data so that the device can be used to isolate problems with loop detector systems. These procedures would enable the signal technician to:

1. Evaluate the condition of a loop detector system at any point in its life cycle (preventative maintenance).

2. Predict the failure of a system before it fails.

3. Isolate failures to the loop, leadin, amplifier or splices.

4. Eliminate crosstalk problems.

5. Determine the cause of intermittent behavior.

<u>Recommendations:</u> One of the primary purposes of this document is to provide the signal technician with a better set of tools. Better maintenance is the result hoped for, and better maintenance means more reliable operation. The importance of having reliable detectors has been emphasized by several jurisdictions. Many consider the vehicle detector to be the weakest link in the chain of traffic control, and if the capability of the traffic control computer is to be utilized, more dependence on the detector is inevitable. It is therefore suggested that the Section titled "To the Maintenance Technician" be adopted and distributed to the maintenance functions of your jurisdictions.

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TO THE MAINTENANCE TECHNICIAN

Table of Contents

INTRODUCTION

The Indicator Controls Corporation (ICC) Loop Tester was chosen for evaluation because of its ability to measure small changes in inductance. Though the techniques described in this report,

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were written primarily for use with the ICC tester, they are general enough to be used with any device which measures frequency and contains its own loop oscillator driver circuit (where frequency depends on parallel capacitance and loop inductance). Such a device must, however, measure frequency with a resolution of 1 hertz or less.

DESCRIPTION OF THE TESTER'S OPERATION

Theory: The tester consists basically of two parts: A loop oscillator driver and a frequency counter. The frequency of the loop oscillator driver is dependent on the resonant frequency of the parallel combination of the tester's internal capacitance and the loop-leadin system's inductance. The frequency counter displays the frequency of the loop oscillator with a resolution of 1 Hz.

Anput/Output: Input/Output to the loop tester is through a standard loop detector M.S. series plug, or banana jacks. The M.S. plug is convenient, since the tester can be plugged directly into a standard detector harness. No other connections are necessary for basic measurements. A switch is provided to put in a vehicle call through the harness being tested.

An adaptor harness and auxilliary input jacks are provided so that the tester may e used as a frequency meter or be used for loops not having the standard M.S. connectors. The readout consists of six 7-segment LED (Light Emitting Diode) digits.

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The frequency of the loop oscillator-driver appears to drift with temperature changes, especially when it is first turned on. Since the left side of the tester box is used for the series regulator heat sink, there is considerable heating. When the box is used in an outdoor area, such as in an open controller cabinet where it is subject to cool breezes, it drifts in the order of 1 to 10 Hz per minute. Insulating the box from drafts helps its stability.

Because the ICC tester's loop oscillator normally operates at high frequencies (greater than 100 kHz) and because inductance measurements become somewhat unpredictable at these frequencies, a modification is recommended. A single pole single throw slide switch and a parallel capacitor should be added to bring the operating frequency down to the less than 100 kHz range.

Note that the capacitance value is now .0056 μf but would be .056 μf with the parallel capacitor added (see capacitance change modification, Figure 7). Two sets of graphs are provided (1 set for each of the two capacitance values) giving the value of "effective" inductance corresponding to the frequency of oscillation of the loop-leadin system. See Figure 6.

APPLICATION NOTES

<u>Basic Loop Check</u>: A good loop-leadin system will resonate at a frequency between 25 and 80 kilohertz (loop tester with internal capacitance of .056 μf see Figure 7).

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1. With the loop attached to the tester's loop input, note the resonant frequency. A frequency between 60 and 120 Hz indicates an "open" circuit in the loop, leadin or splice.

2. If the resonant frequency falls in the range of 25-80 kHz determine the inductance of the loop-leadin system using the tables, Figure 6. (Note the value of parallel capacitor in the tester.) Using the graphs, Figures 1 and 2, determine what the expected values of inductance for this particular loop-leadin system would be. These values should agree within, say, 20%.

3. If the system does not pass checks 1 or 2, the loop may be checked at the pull box closest to the loop by opening the splices. This procedure will isolate the problem to the loop, leadin or splices. If power is not available at the pull box, attach a bench test loop to the leadin and measure the resonant frequency at the amplifier end. Look up the inductance associated with that frequency, subtract the inductance of the bench test loop and compare the difference with the exprected inductance of the leadin, Figure 2. If these values are within 20%, the problem is in the loop or splices. If the splices appeared good the loop is probably defective. The splices may be cleaned and resoldered and checks 1 and 2 repeated to verify that the loop is defective.

4. Also see new installation acceptance tests.

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Measurement of Inductance: The inductance of a loop may be found by measuring its resonant frequency.

1. Record frequency of oscillation of loop-leadin system. Do not be concerned with the drift in frequency; the loop oscillator will drift from 1 to 10 Hz per minute.

2. Find the inductance corresponding to that frequency by using the graph, Figure 6 (note any parallel capacitance that may have been added to the loop terminals).

3. Look up the expected value of inductance of the loop (without leadin). The difference should be leadin inductance. Check against expected leadin inductance. See graphs, Figures 1 and 2.

Measurement of Changes of Inductance: Change in inductance is proportional to change in resonant frequency.

1. Record the no vehicle frequency, f_1.

2. With the test vehicle on one or more of the loops, record the new frequency, f_2.

3. The difference between the two frequencies is a measure of the change in inductance due to the presence of the vehicle according to the relation $\frac{\Delta f}{f} = 1/2 \ \frac{\Delta L}{L}$ (this is an approximate relation, valid for % change in inductance up to 10% and for loop Q greater

than 5. Multiply the percent change in frequency $\frac{f_2-f_1}{f_1}$ by 2 to get the % change in inductance.

4. See New Installation Acceptance Tests for a comparison of the change in inductance to an ideal value.

New Installation Acceptance Tests: A new installation should have near ideal inductances and sensitivity.

1. Measure the resonant frequency of the loop-leadin system.

2. Find the inductance from the graph, Figure 6.

3. Compare this inductance with expected values found in the expected inductance values graphs, Figures 1 and 2. The values should not differ by more than, say, 20%.

4. Using the motorcycle model measure the change in frequency due to the presence of the model in the center of the (one of the) Loop(s).

5. Find the expected % frequency change for the loop-leadin configuration being tested. (From Table 1 the measured change should not be less than the expected value by more than 20%, see example, Figure 5.)

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Troubleshooting Cross Talk Problems: Cross-talk can be the result of two loop-leadins sharing common conduit and operating at close to the same frequencies. Two loops installed within a few feet of each other may also tend to cross-talk.

1. Using the aux. input to the tester measure the operating frequency of the loop detectors suspected of cross-talking.

2. If the operating frequencies of two or more detectors are less than 1 to 2 kilohertz different and they share one or more conduit runs, they are likely to cross-talk.

3. If the amplifiers have a range switch or other means of selecting operating frequencies, adjust them so that their operating frequencies are separated by at least 2 kilohertz (more separation may be necessary).

4. If no adjustments are available on the amplifiers, adding parallel capacitors to the field terminals may shift the operating frequency adequately. A good quality capacitor may be used, such as polycarbonate or ceramic, which has a reasonable temperature stability coefficient. The size of capacitor required to shift the resonant frequency by about 2 kilohertz is .005 µf. This value is only "ballpark"; actual values required may vary from .003 to .007 µf. Note that this procedure cannot be used on amplifiers where the operating frequency is independent of loop inductance.

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Troubleshooting Locked Call Problems: Locked calls may be caused ty abrupt changes in the inductance of the loop-leadin system.

1. Record the resonant frequency of the loop (no vehicle).

3. Monitor changes in frequency due to vehicles, recording resonant frequencies between vehicles.

3. Look for abrupt changes in the no vehicle resonant frequency. Such changes can cause locked or missed calls.

4. Look for a decreasing resonant frequency due to the presence of a vehicle. A decreasing resonant frequency indicates an increased inductance which can cause locked-calls or unreliable operation (normally the inductance of a loop decreases with the presence of a vehicle).

5. Either of the above problems may be isolated by opening the splices at the pullbox nearest the loop. An abrupt change in the no vehicle resonant frequency, or a decreasing frequency when a vehicle is present is most likely caused by the loop or loop-leadin not being securely attached to the pavement, but may also be caused by movement of the pavement in relation to the shoulder or by breakdown of the splices. The loop and loop-leadin should be inspected for signs of mechanical breakdown. Inspect the splices for signs of breakdown of the soldered joint. If there is no sign of solder breakdown, check for signs of moisture entry

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into splice. Any of these might be the source of the problem.

A bench test loop or similar inductance may be hooked to the loop and the leadin and the resonant frequency monitored at the amplifier end (repeat steps 1 and 3). If there is no rapid shift in frequency, the problem has been isolated to the loop or to the splice. If cleaning and resoldering the splice does not cure the problem, the loop must be replaced (splices should be taped in such a way that moisture is kept out).

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The contents of this article reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This data does not constitute a standard, specification, or regulation nor do they constitute an endorsement of the ICC Loop Tester.

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TABLE 1

EXPECTED VALUES OF CHANGE IN INDUCTANCE DUE TO A HONDA 100 OR THE MOTORCYCLE MODEL

Loops: 6 feet by 6 feet 3 turn loops made with 12 AWG solid wire

Expected Changes: Loops without leadins

EXPECTED INDUCTANCE	VALID RANGE OF MEASURING FREQ.	EXPECTED % CHANGE FREQ.	% CHANGE IN INDUCTANCE	LOOP CONFIGURATION (LESS THAN 15'LEADIN)
μhenries				
79	34-100 kHz	.12%	.24%	1-6'x6' (square)
158	24-75 kHz	.06%	.12%	2-6'x6' series
40	47-150 kHz	.06%	.12%	2-6'x6' parallel
235	19-50 kHz	.04%	.08%	3-6'x6' series
80	34-100 kHz	.03%	.06%	4-6'x6' ser.-par.-comb.
312	10-30 kHz	.03%	.06%	4-6'x6' series

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Table 1 (Continued)

LEADINS: Adding leadin reduces these percent changes according to formulas 1 and 2 below:

% Change loop freq. $\equiv$ % Δf_L ($\Delta \equiv$ change)

% Change (loop + leadin) freq. $\equiv$ % Δf_{L+l}

Definitions: % Change in loop inductance $\equiv$ % ΔL_L

% Change in loop + leadin inductance $\equiv$ % ΔL_{L+l}

Loop inductance = L leadin inductance = l

Then 1: $\% \Delta F_{L+l} = \% \Delta F_L \times \frac{L}{L+l}$ For frequency change

2: $\% \Delta L_{L+l} = \% \Delta L_L \times \frac{L}{L+l}$ For inductance change

So changes are reduced by the ratio of loop to total inductance.

Lead-in used is State of California Standard Specification Type A (Sec. 86-5.01A(4); IMSA Specification: 19-1).

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FIGURES

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Figure 1

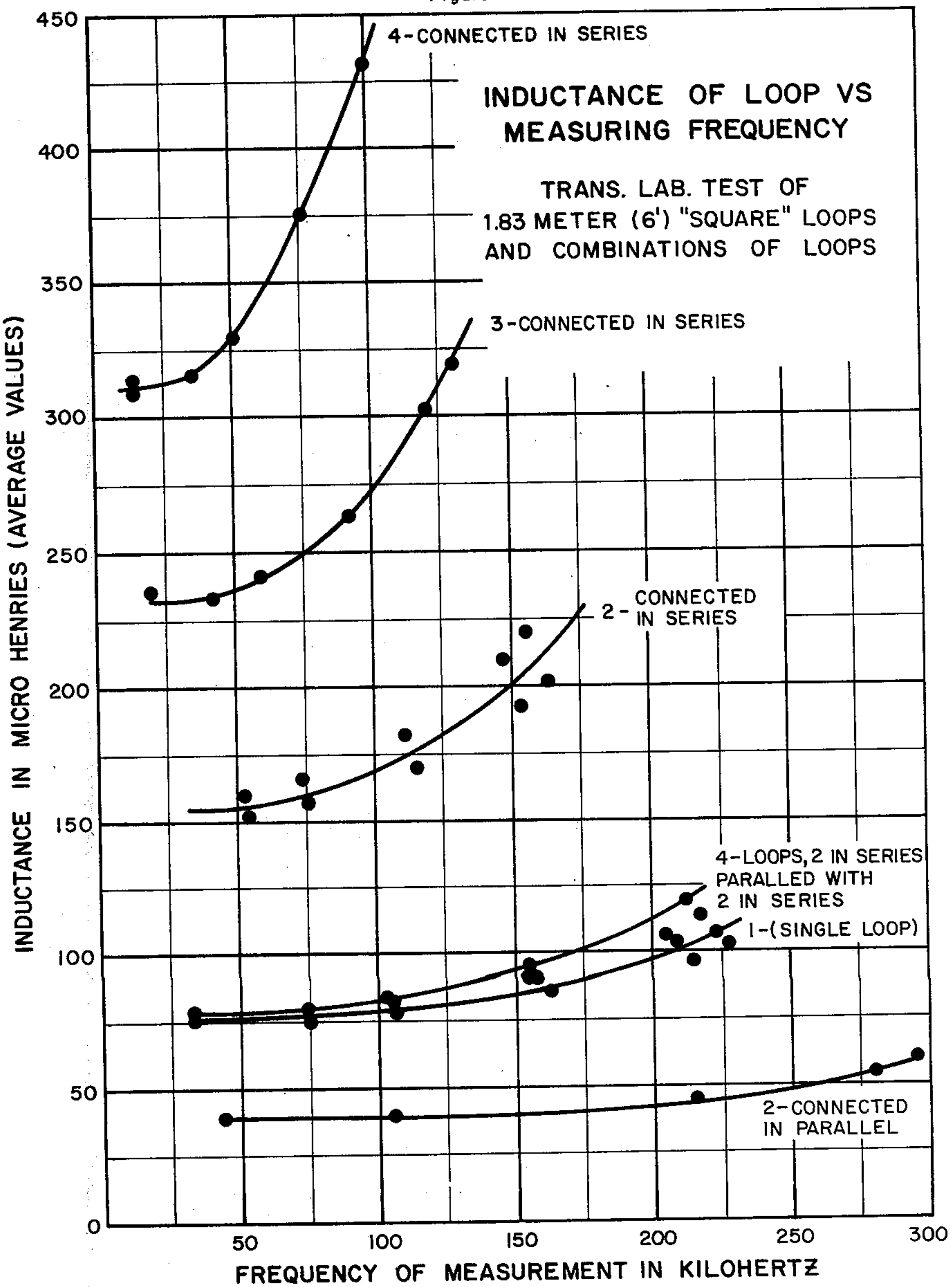

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Figure 2

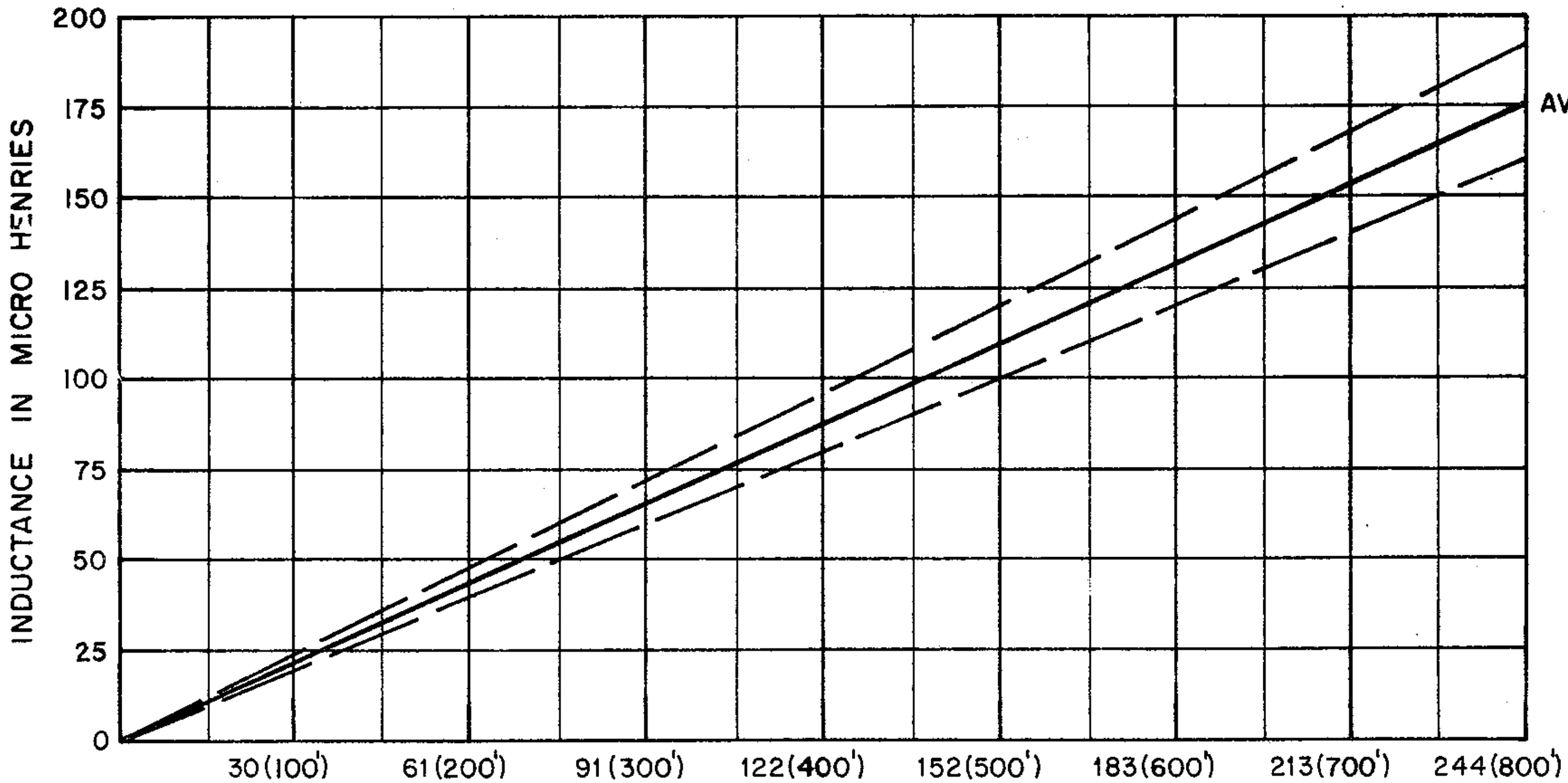
INDUCTANCE OF LEADIN (EFFECTIVE INDUCTANCE) VERSUS LEADIN LENGTH

NOTE 1: UP TO 3 METERS (10') OF LOOP LEADIN IS CONSIDERED PART OF LOOP.

NOTE 2: THIS CURVE IS VALID ONLY FOR FREQUENCIES BELOW 80 KILOHERTZ

FORMULA: L=.72 x l (OR L=.22 x l)

[INDUCTANCE (microhenries) = .72 x LEADIN LENGTH (Meters) OR .22 x LEADIN LENGTH (Feet)]



[TOTAL LENGTH LOOP TO CABINET MINUS 3 METERS (10') LOOP LEAD]

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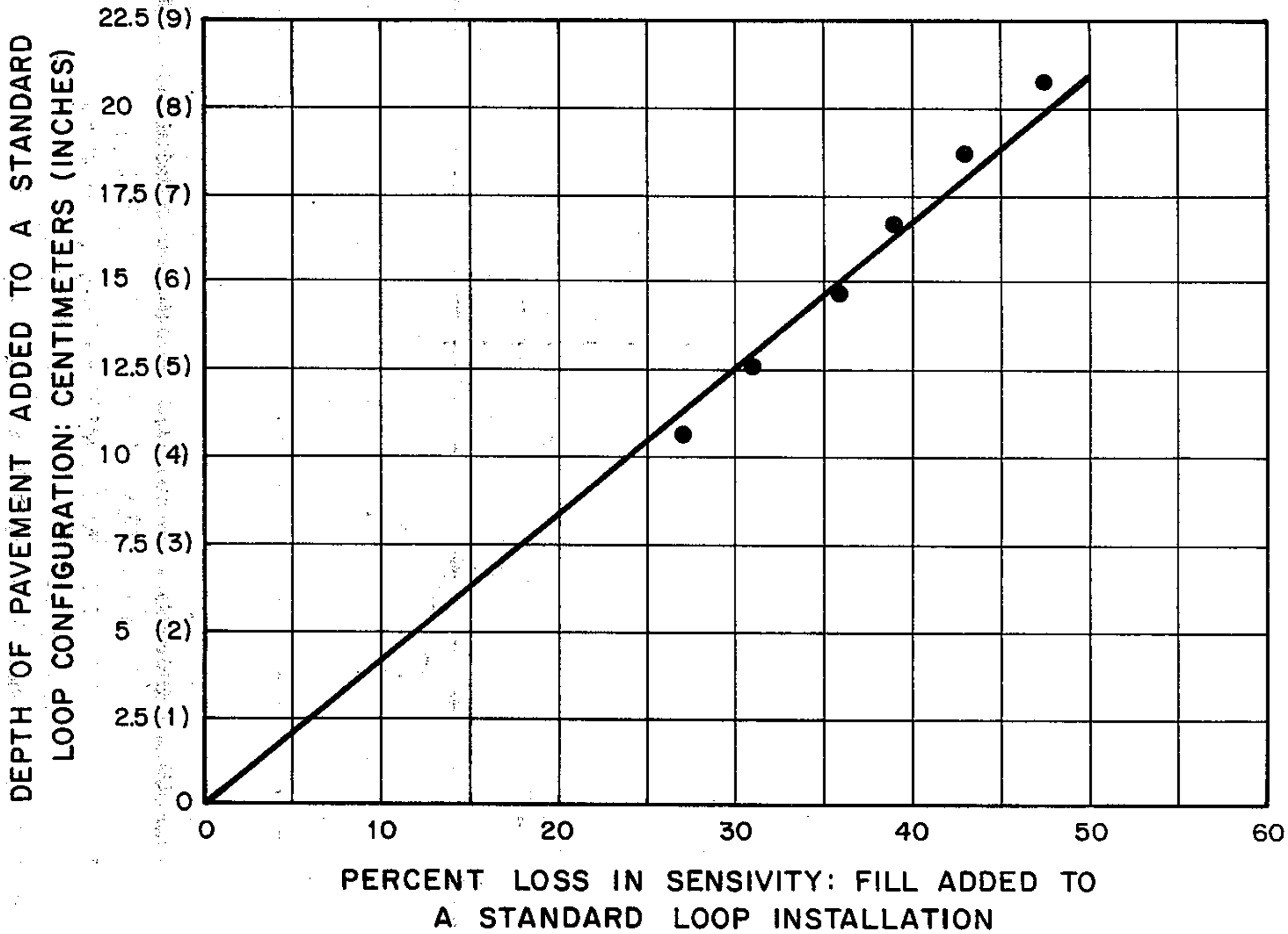
Figure 3



LOSS IN SENSITIVITY DUE TO FILL OVER LOOP
(HONDA 100 USED AS TEST VEHICLE)

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Figure 4

SHORTED TURN VEHICLE MODEL, TO SIMULATE 100CC HONDA MOTORCYCLE

MATERIAL: 13mm (1/2" PLYWOOD, EXTERIOR GRADE)

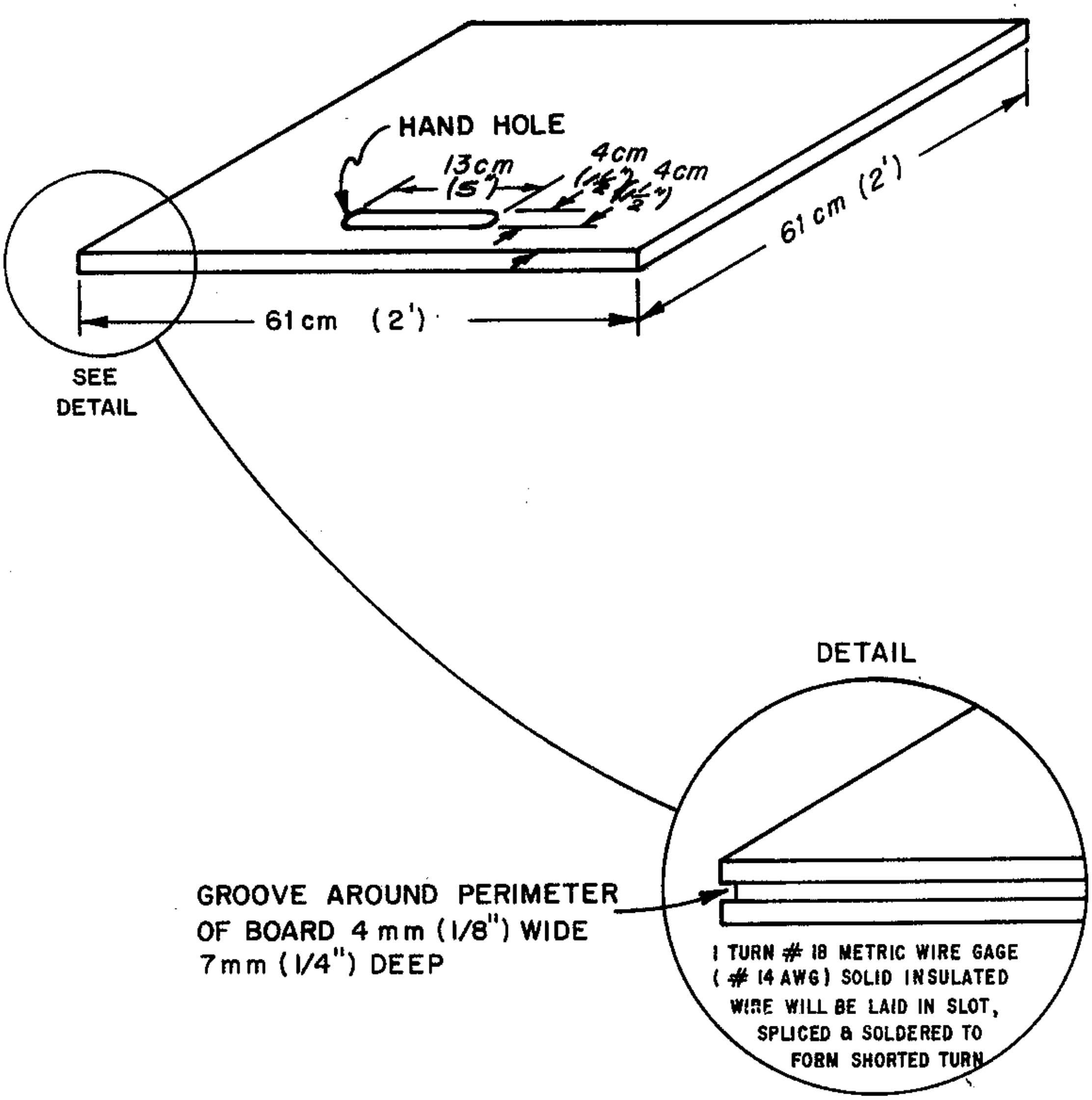

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Figure 5

Expected Values of Change in Frequency

A SAMPLE CALCULATION

Changes in frequency were measured when the motorcycle model was placed on one loop of 4 - 1.83 m (6 ft) square series - parallel connected loops, with 76.2 meters (250 ft) of leadin.

Resonant frequency (no vehicle)	57994
Resonant frequency (with motorcycle model)	58005
count change (subtract)	11

% change in frequency = 11/57994 x 100

= .189%

Expected value:

From table: 4-1.83 m (6 ft) square series parallel comb. = .03% Δf

Inductances of loop and leadin:

Loop = 80 μh; leadin = .72 x 76.2 M (.22 x 250 ft) = 55 μh

Then expected % change is

$$\% \Delta f_{L+l} = f_L \times \frac{L}{L+l}$$

$$\% \Delta f_{L+l} = .03 \times \frac{80}{80+55}$$

$$\% \Delta f_{L+l} = .0178\% \text{ or } .036\% \Delta L_{L+l}$$

The difference between the expected and measured values is about 6% (found by subtracting the two %ΔL's, .0189 and .0178, and dividing by the expected value) others may vary by as much as 10 - 15%.

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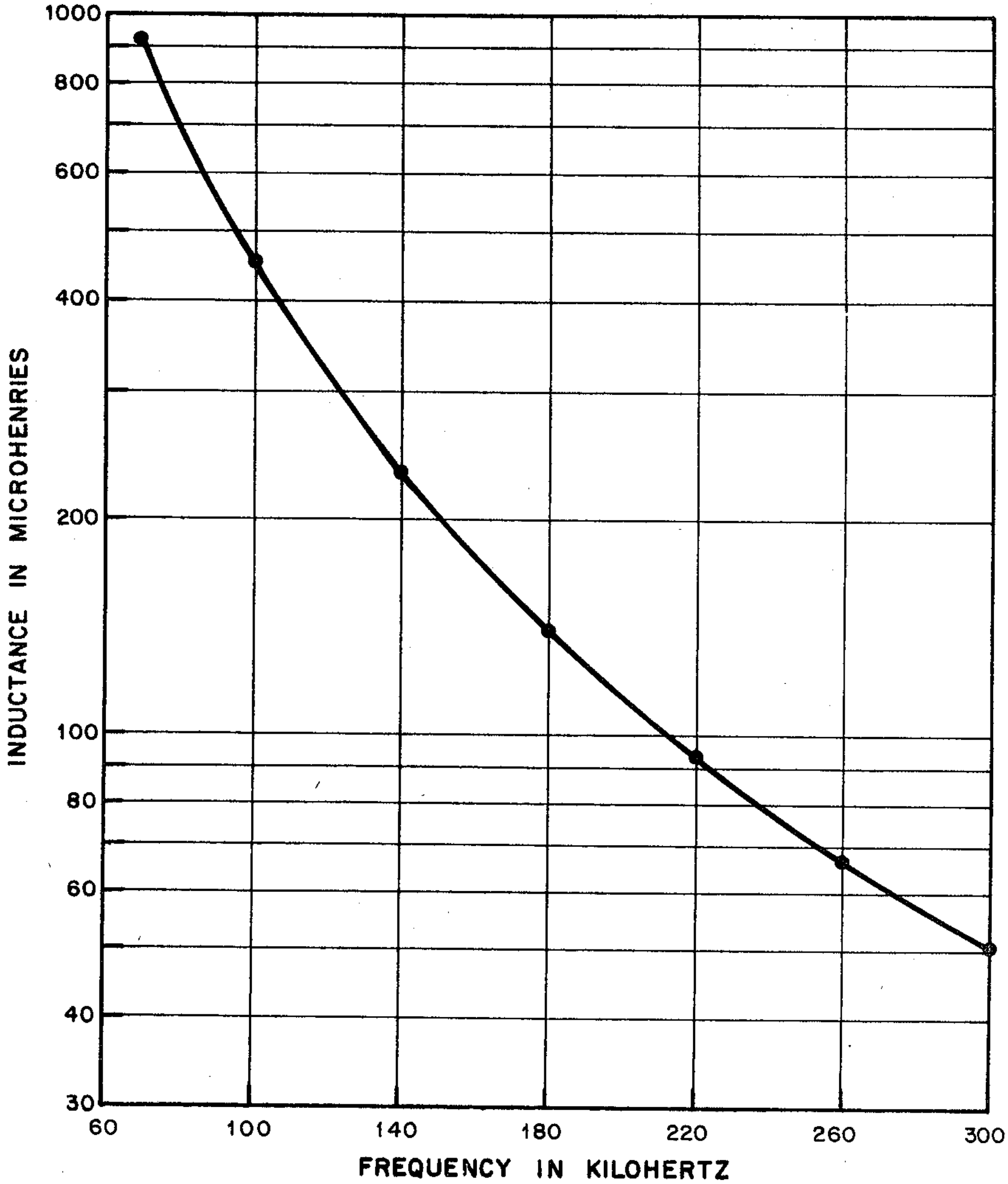
Figure 6



INDUCTANCE VERSUS RESONANT FREQUENCY
FOR CAPACITANCE OF .0056 MICROFARAD

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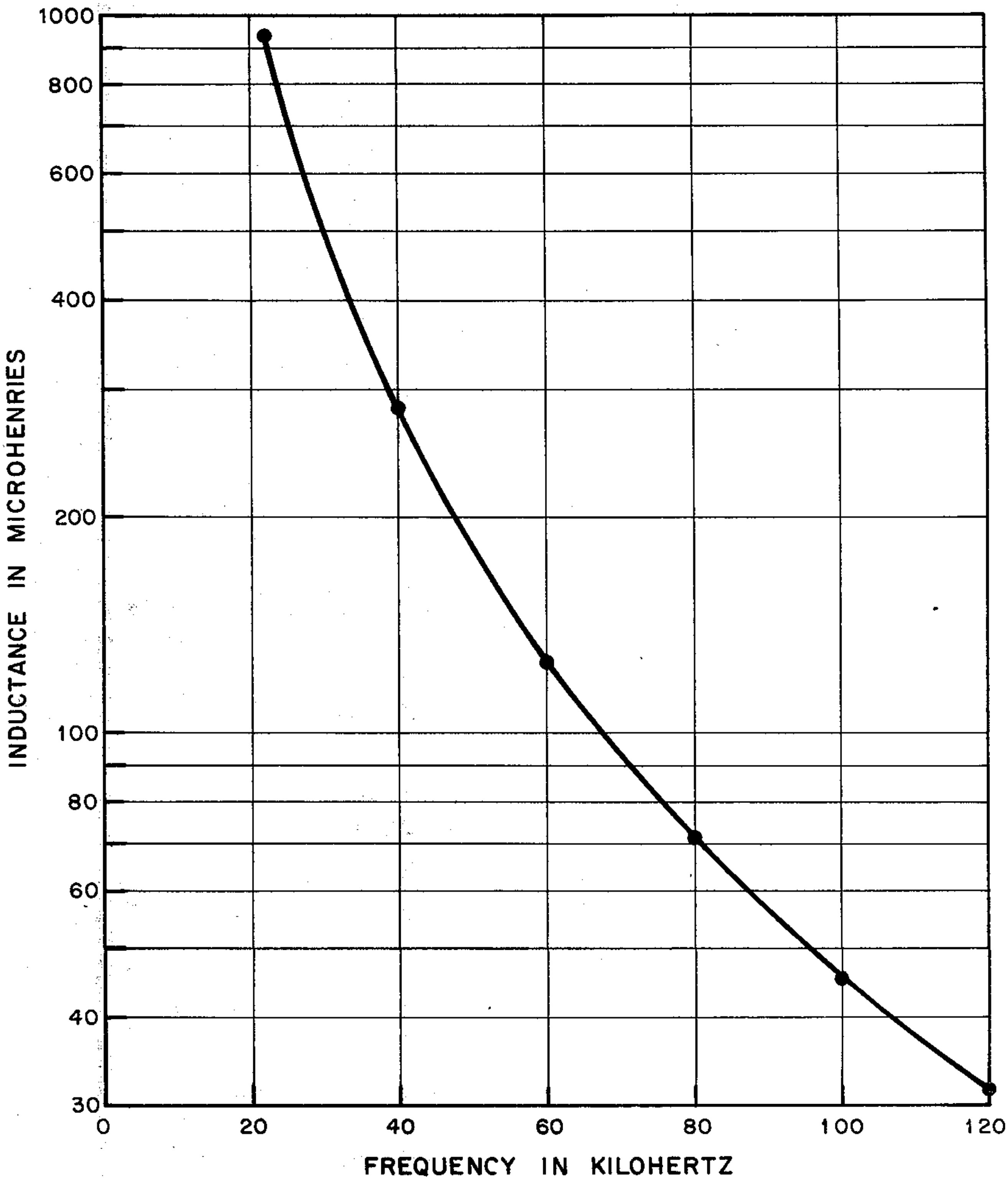
Figure 7



INDUCTANCE VERSUS RESONANT FREQUENCY
FOR CAPACITANCE OF .056 MICROFARAD

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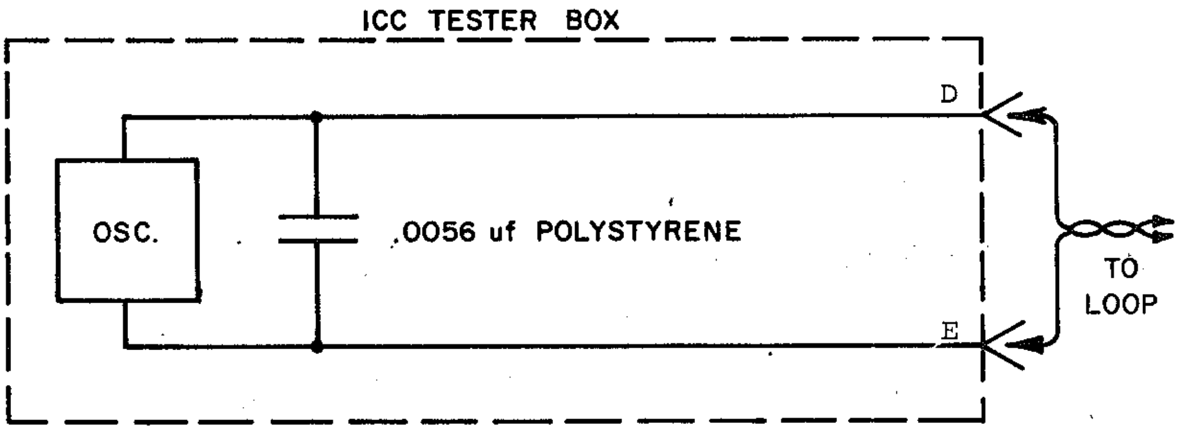
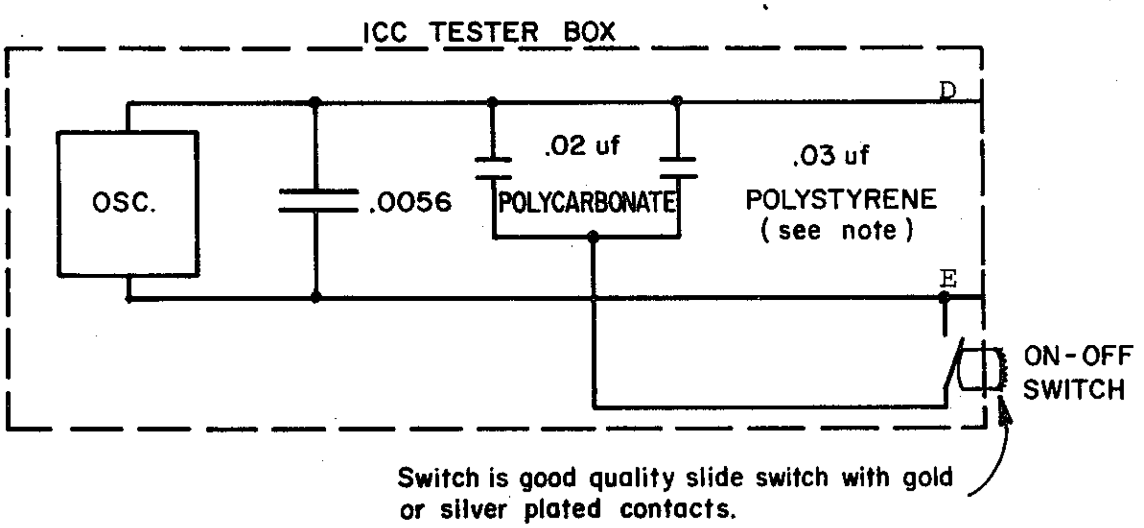
Figure 8

CAPACITANCE CHANGE MODIFICATION

1. EXISTING CIRCUIT



2. MODIFIED CIRCUIT



NOTE: Polystyrene and polycarbonate capacitors have opposite temperature drift coefficients. The two values shown were chosen to minimize temperature drift. These values may be varied by as much as ± .004 µf, but the parallel combination of the two must add to as close to .0504 µf as possible.

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