3

BDX-613-877

MICROHM DECADE RESISTOR

Technological Spinoff Report

G. E. Kator, Project Leader

May, 1973

Prepared for the
United States Atomic Energy Commission
Under Contract Number AT(29-1)-613 USAEC

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

MICROHM DECADE RESISTOR

BDX-613-877

May 1973

Project Leader
G. E. Kator
Department 415

Technological Spinoff Report

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Technical Communications

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

MICROHM DECADE RESISTOR

BDX-613-877, UNCLASSIFIED Technological Spinoff Report, May 1973

Prepared by G. E. Kator, D/415

A microhm decade resistor with a minimum resolution of 1 microhm per step has been designed and built at Bendix Kansas City Division. Waidner-Wolff (or shunted) decades provided the desired small incremental changes in resistance.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission

Contract Number AT(29-1)-613 USAEC

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS

Section	Page
SUMMARY	9
DISCUSSION	11
SCOPE AND PURPOSE	11
ACTIVITY	11
<u>Design and Construction</u>	11
<u>Evaluation</u>	14
CONCLUSION	16

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

ILLUSTRATIONS

Figure		Page
1	Bendix-Designed Microhm Decade Resistor (P-76332)	12
2	Relationship Between Resistors	13
3	Resistance Values for Decade Construction	15

TABLE

Number		Page
1	Resistance Change Per Decade Step	16

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

SUMMARY

The calibration of resistance thermometer bridges, such as Type G-1 and G-2 Mueller Bridges which have low-resistance and high-precision rheostat arms, requires the capability to generate resistance changes in increments of 10 microhms or less. Switch contact resistance, coupled with the inherent difficulty of measuring and assembling low-value, two-terminal resistors, limits normal decade resistors to a minimum resolution of 0.01 ohm per step. The desired small incremental changes in resistance may be obtained by using Waidner-Wolff (or shunted) decades. Such an approach was used in the design of a decade resistor with a minimum resolution of 1 microhm per step.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

DISCUSSION

SCOPE AND PURPOSE

The purpose of this project was the development of a decade resistor having a minimum resolution of 1 microhm per step. The study included the use of Waidner-Wolff (or shunted) decades to obtain small incremental changes in resistance.

ACTIVITY

Design and Construction

The technique of shunting a decade resistor provides two features which facilitate achieving small incremental resistance changes:

- The shunting significantly reduces instabilities in circuit resistance due to switch contact resistance; and
- The decade may be designed so that the individual step resistor values are sufficiently large to permit measuring and installation as two-terminal resistors with good precision.

Disadvantages of this type of circuit are as follows:

- With the decade resistor set to zero, the residual resistance in the circuit is approximately equal to the shunting resistance value; and
- With a shunted decade arrangement, to obtain a linear resistance change with each step of the decade each individual step resistor must be a different value.

The Bendix-designed microhm decade resistor instrument is shown in Figure 1, and the general configuration of shunted decade resistors is shown in Figure 2.

Figure 1. Bendix-Designed Microhm Decade Resistor

Figure 2. Relationship Between Resistors

With reference to Figure 2, the relationship between resistors within a decade and between decades is

$$R_{D1} = \frac{R_S^2 R_D + S (R_S + R_P + R_D) (R_S + R_P)}{R_S^2 - S (R_S + R_P + R_D)} \quad (1)$$

where

R_D = The total resistance stepped into the decade circuit,

S = Desired ohmic change in resistance between points A and B per decade step (such as $0.1\Omega/\text{step}$, $0.01\Omega/\text{step}$), and

R_P and R_S = Fixed resistors chosen to give real values to the step resistors in R_D .

$$R'_S = \sqrt{(R_S + R_P + R_{DT}) S'} \quad (2)$$

where

S' = Desired ohmic change in resistance for the next higher or lower decade,

R_{DT} = Sum of the nine resistors of R_D , and

R'_S = Ohmic value of the shunting resistor corresponding to the decade choice for S' .

$$R_P + R_S = R'_P + R'_S \quad (3)$$

For given values of R_P , R_S , and S , the resistance value for each step of R_D can be calculated by using Equation 1 (step value = $R_{D1} - R_D$). After the value of each step of R_D has been determined, values for R_S and R_P for the remaining decades can be determined by using Equations 2 and 3.

Use of Equations 1, 2, and 3 will result in decades where the ohmic change of each decade (such as $0.01\Omega/\text{step}$, $0.001\Omega/\text{step}$) is determined by values of R_S and R_P . Corresponding step values of R_D are the same for each decade.

A certain amount of trial and error was involved in arriving at values for R_S and R_P which would yield nominal resistance values for the individual steps of R_D . The task can be simplified through the use of a computer or programmable calculator. The resistance values used for the construction of this decade are shown in Figure 3.

The resistors (ESI Type RF4) were soldered to the switches (Cole Instruments Type 221-230-121) which were mounted on a panel. The switches and resistors were enclosed in a metal case to provide electrostatic shielding when required. This assembly was then placed in a wooden case for appearance and to provide a degree of thermal lagging.

Evaluation

The accuracy of the resistance change obtained by the switching of each decade was evaluated using a Leeds & Northrup Model 4398 Double Ratio Set. This instrument is capable of resolving one part per million (ppm) change in resistance.

First, the residual resistance of the decade resistor was measured and found to be approximately 4.504 ohms. The minimum resolution of the decade resistor is 1 microhm per step, which represents a resistance change of approximately 0.22 ppm of 4.504 ohms, an amount beyond the resolution of the double ratio set. Therefore, the 10 microhm-per-step decade (approximately 2.2 ppm per step) was the lowest decade upon which a direct evaluation could be performed.

To evaluate the 10 microhm-per-step decade, the detector used with the double ratio set was first calibrated to give one major division deflection for each step of the lowest dial of the double ratio set (approximately 1 ppm). Each

Figure 3. Resistance Values for Decade Construction

step of the 10 microhm-per-step decade was then switched into the circuit and the amount of detector deflection was read. This technique was also used to evaluate ten steps of the 1 microhm-per-step decade. From this data, the resistance change for each step of the 10 microhm-per-step decade and for ten steps of the 1 microhm-per-step decade was calculated. Results are given in Table 1.

For the decades 100 microhm-per-step and above, direct measurements of the resistance change per step were made with the double ratio set. Results are given in Table 1.

Table 1. Resistance Change Per Decade Step

Setting	Decade, Each Step				
	0.01 Ω	0.001 Ω	0.0001 Ω	0.00001 Ω	0.000001 Ω
1	0.0100017	0.0009993	0.0001022	0.0000102	
2	0.0100021	0.0010038	0.0000977	0.0000102	
3	0.0100021	0.0010002	0.0001022	0.0000102	
4	0.0099990	0.0009993	0.0000977	0.0000102	
5	0.0100061	0.0010029	0.0001022	0.0000102	
6	0.0100021	0.0009993	0.0001022	0.0000102	
7	0.0100017	0.0009953	0.0000977	0.0000102	
8	0.0100119	0.0010042	0.0001022	0.0000102	
9	0.0100017	0.0010024	0.0001022	0.0000102	
X	0.0100021	0.0009949	0.0000977	0.0000102	0.0000102*
*Resistance change for ten steps.					

CONCLUSION

The design goal for the decade resistor was a resolution of 10 microhms per step. Results of the evaluation show that this goal was reached. Although direct confirmation was not possible, there is good reason to assume the decade resistor has a resolution of 1 microhm per step.