# PROGRAMMABLE GUARDED COAXIAL CONNECTOR PANEL

**Presenter/Author**

Lisa L. Kile†
National Institute of Standards and Technology‡
Gaithersburg, MD 20899
Phone: (301) 975-4241 FAX: (301) 926-3972

## Abstract

A programmable guarded connector panel using coaxial connectors has been specifically designed for an automated measurement system for the comparison of four-terminal resistors. A computer controlled XYZ positioning system is used to move a 4-connector Z arm over a panel of 72 coaxial connectors mounted in the XY plane. This provides for 30 four-terminal channels. The outer shields of the connectors are electrically isolated from one another to allow the shields to be driven at guard voltages to suppress errors caused by leakage currents. The resistance repeatability of the plug-socket connections including resistance variations of 12 m of AWG 12 connecting cable is typically 10 $\mu\Omega$. Variations of thermoelectric voltages over a 10-minute measurement period of the plug-socket connections are typically less than 10 nV. This automatic switching system may be useful for other types of precision measurements where guarding, contact resistances, and thermoelectric voltages are critical factors.

## Introduction

Programmable switches or scanners are important components of automated measurement systems used to calibrate standard resistors.[1-4] The performance characteristics of these switches can introduce errors that limit the useful resistance range of operation of these automated systems. Usually at low resistance ranges, the limiting factor associated with programmable switches is large and varying thermoelectric voltages; while at high resistance ranges, the limiting factor is the insulation resistance of the switches. Contact resistance repeatability is another factor that is

---

†Co-operative electrical engineering student at the University of Maryland, College Park, MD 20742.

‡Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce. 

important for automated systems whose operating principle is based on a bridge method instead of a potentiometric method.

The National Institute of Standards and Technology (NIST) is developing an automated resistance bridge system to replace its manual system for calibrating high-quality 10 kΩ standard resistors. The goal is to develop a system equal or superior in precision and accuracy to the existing system. To achieve this goal, the programmable switch requirements include: a) constant thermoelectric voltages $\leq 10$ nV, b) effective insulation resistance $\geq 10^{13}$ Ω, and c) contact resistance repeatability $\leq 10$ μΩ. To our knowledge, no commercial switch is available that satisfies these requirements.

Consequently, a programmable guarded connector panel using coaxial connectors has been specifically developed for this automated system. These coaxial connectors are of the same type that are in use with the manual system. This assures that this automated switching system should not contribute any increase in the uncertainty of the measurements when compared to the manual system. In fact, an improvement in the measurement uncertainty is expected with a more controlled and repetitive switching system.

## Description of Switching System

The main sub-components of the switching system include: a) the programmable XYZ positioning stages, b) the XY panel of 72 coaxial plug connectors, c) the Z panel of four coaxial socket connectors, and d) the digital position display. An over-all view of the system is shown in Fig. 1.

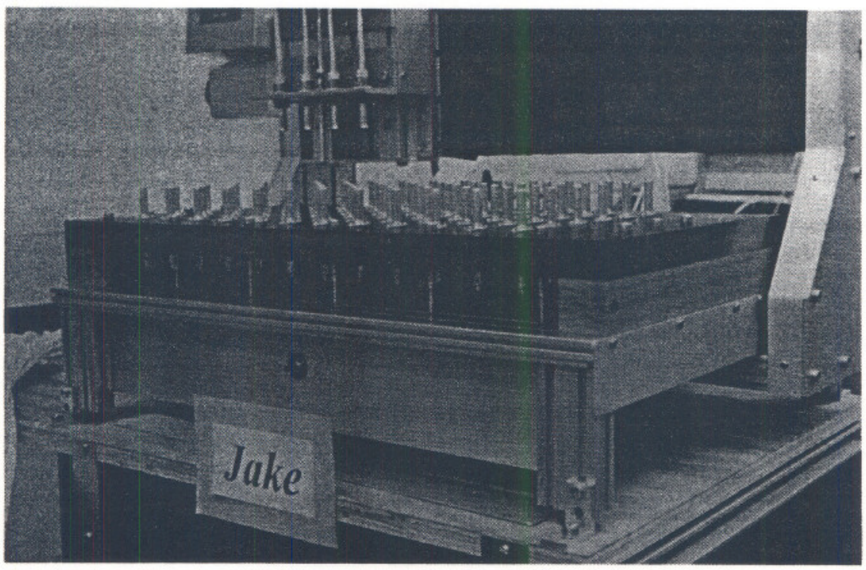


Fig.1 Photograph of programmable switching system.

a) Programmable XYZ positioning stages - This assembly is a commercial unit with a microprocessor-based controller designed for direct interfacing to a computer via a standard RS-232C serial port. Each stage is driven by a stepping motor attached to a 2 mm pitch ball screw. Double rail guides are used on each stage to improve positional accuracy. The XY travel area is 40.0 cm x 25.0 cm, and the Z travel is 10.0 cm. Linear resolution of each axis is 0.005 mm/step. Positional repeatability and uncertainty are specified as ± 0.01 mm and 0.1 mm/300 mm, respectively. All axes are provided with home reference switches with ± 0.01 mm repeatability. Maximum programmable speed is set at 5 cm/sec. A separate controller unit contains the stepping motor amplifiers, and the 3-axis controller and interface card with optically isolated inputs and outputs.

b) XY connector panel - This panel is constructed out of Delrin® material with outer dimensions of 61.0 cm x 30.5 cm x 1.90 cm. It contains 72 coaxial plug connectors along 6 rows of 12 each. This provides for 30 four-terminal channels; five channels along each row. The distance between adjacent connectors along or between rows is 4 cm, which results in a travel area of 32 cm x 20 cm. The plug-type coaxial connectors have sterling silver inner conductors and polytetrafluoroethylene (PTFE) insulation. The outer shields of the connectors are electrically isolated from one another, which allows the shields to be driven at a guard voltage to suppress leakage errors. In the center of each set of four connectors along a row is a guide hole of 6.35 mm OD.

c) Z connector panel - Four mating coaxial socket connectors are mounted in-line on a fiberglass-based composite angle bracket attached to the Z positioning stage. The mounting holes for these four connectors are oversized to allow for slight movement in the XY plane. PTFE washers are used on each side of the bracket to facilitate this movement. Below the bottom PTFE washer is an O-ring to allow for slight movement along the Z axis. A set-screw type of collar along with the connector mounting flange is used to hold the assembly in place on the angle bracket as shown in Fig. 2. In the center of this assembly is a guide rod which extends 3.5 cm below the end of the socket connectors to protect them from damage. This rod is free to move in a housing and, on contact, can trigger a stop switch located on top of the housing. If this Z stage is correctly positioned above a set of connectors on the XY panel and in the descending mode, the guide rod will pass through the guide hole on the XY panel and the connectors will mate properly. If there is a misalignment of the Z stage, the guide rod will hit the top of the XY panel or a plug connector, and trigger the stop switch which sends an interrupt signal to the computer.

d) Digital position display - A digital panel meter indicates one of the thirty possible connector positions that can be engaged by the Z stage. The position number corresponds to a voltage reading on the meter that is connected to a voltage divider circuit energized by a Zener reference diode. A magnet is attached to the end of the Z axis guide rod that closes a Hall-effect switch, mounted on the underside of the XY panel, as it passes through the guide hole. When the guide rod retracts from the guide hole, the Hall-effect switch is opened. Each guide hole has its own Hall-effect switch, which upon closure connects the proper resistance in the voltage divider circuit to indicate a voltage on the digital display that corresponds to the connector position. This voltage is also measured by an A/D I/O adapter card installed in the personal computer.

---

®E.I. DuPont. This identification does not imply recommendation or endorsement by the National Institute of Standards and Technology.

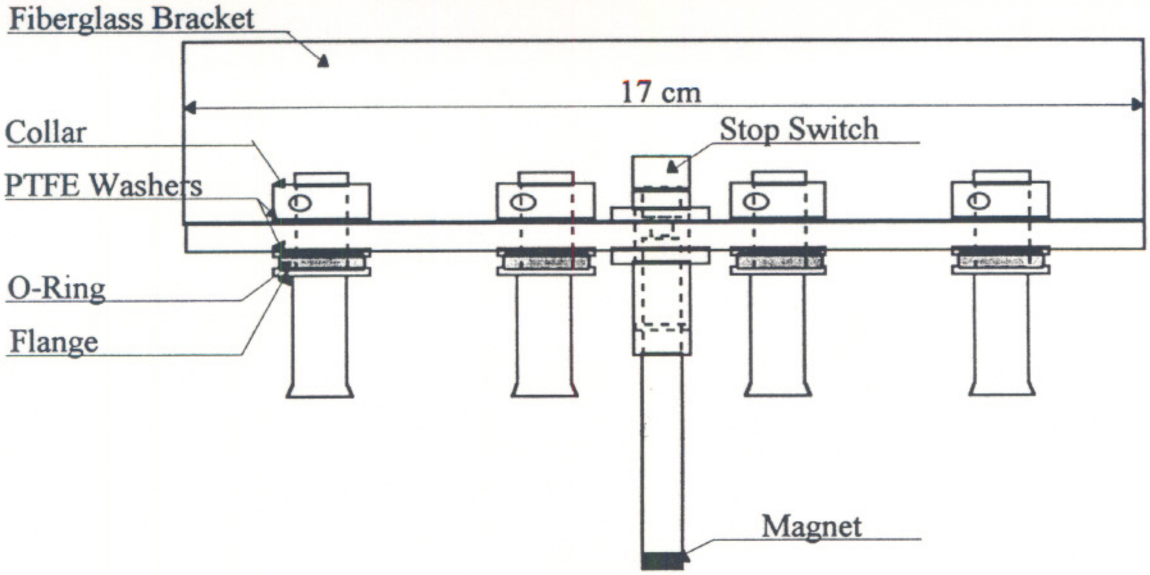


Fig. 2. Drawing of Z connector panel.

## Software

The software is written in BASIC language using "PRINT" and "INPUT" statements to communicate with the XYZ positioning stages. The initial program commands "HOME" the axes and then position the Z stage over position 1 which serves as a reference point. The program reads a position input file which lists the desired connector positions for the measurement run. This input file can list position numbers in any numerical order including duplicate positions. The data from the A/D card is used to record the actual connector position engaged. All data is saved in an output file.

The software checks for an interrupt signal from the stop switch to determine if a misalignment of the Z stage has occurred. Detection of the interrupt signal will activate an error routine which results in the XYZ stages retrieving to the "HOME" position and then returning to the original connector position. If a second error is detected, the program will print an error message indicating the faulty position number, and then terminate the run.

## Measurements

Shielded PTFE-insulated cables of 3 m length are attached to each plug or socket coaxial connector. The cable inner conductor consists of stranded silver-plated copper wires. To check the switch characteristics, adjacent pairs of cables from the XY panel were shorted together at their ends, and either four-terminal resistances or voltages were measured at the ends of the two adjacent pairs attached to the Z stage.

The resistance of plug-socket connections, including the resistance of 12 m of connecting cable (AWG 12), was measured for 36 pairs of connections. Each measurement consisted of 10 operations of the Z stage over a time period of about 10 minutes. The Type A standard uncertainty for a measurement was typically 10 $\mu\Omega$. This agrees with the value given in Ref. 5 ($\pm$ 10 $\mu\Omega$) for the contact resistance repeatability of similar coaxial connectors. The total resistance of a cable pair was nominally 0.075 Ω. Of this total, approximately 0.065 Ω is due to the cable resistance and the remainder is due to the plug-socket connections.

The same cable configurations were used for the measurements to determine the magnitude of the thermoelectric voltages. It is difficult to measure the absolute thermoelectric voltages; however, they are estimated to be less than 30 nV. It is easier to measure variations of thermoelectric voltages over a specified time period. These measurements indicated that over a 10-minute period these variations are typically less than 10 nV.

The insulation resistances of the PTFE-insulated cables and connectors were measured and found to be $> 10^{12}$ Ω. If a guard circuit is used and the guard voltages are within 1% of the main circuit voltages (easily accomplished in practice for the 10 kΩ measurement system), the effective insulation resistance is $> 10^{14}$ Ω.

## Conclusion

NIST has developed a unique programmable switching system which features repeatable contact resistance on the order of 10 μΩ and thermoelectric voltage variations of less than 10 nV. It is a completely shielded system that can be driven at an active guard voltage to suppress leakage errors. It is specifically designed to be used in an automated resistance bridge system for measuring four-terminal standard resistors. However, it may be useful for other automated systems requiring programmable switching with these performance characteristics. It is also designed to withstand voltages of 1 kV or higher.

## References


1. Baker, Kenneth R. and Dziuba, Ronald F., "Automated NBS 1 Ω Measurement System," IEEE Trans. Instrum. Meas., IM-32, No. 1, Mar. 1983, pp. 154-158.

2. Marshall, James A. and Marshall, Thomas A., "Improving Automated Measurements for Voltage, Resistance, and Temperature," Paper delivered at the NCSL Conf., Aug. 1991.

3. Garcia, Kenneth L., "Autores - Automated Resistance Maintenance Program," Paper delivered at Meas. Sci. Conf., Jan. 1992.

4. Faulkner, Neil, "An Automated System for the Comparison of Resistance Standards from 1 Ohm to Several kOhms," Paper delivered at the Meas. Sci. Conf., Jan. 1992.

5. Dziuba, Ronald F. and Dunfee, Bernadine L., "Resistive Voltage-Ratio Standard and Measuring Circuit," IEEE Trans. Instrum. Meas., IM-19, No. 4, Nov. 1970, pp. 266-277.