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Design of a current switching system for high accuracy current sources in AC-DC Transfer applications

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Abstract. A current switching system for AC-DC transfer applications using Single Junction Thermal Converters (SJTC) was designed and tested at Instituto Nacional de Metrología (INM). This switch design can directly commute between a DC reference current source and an unknown AC current source generated by high accuracy calibrators such as Fluke 5720A and Fluke 5730A. Two vacuum latch relays with an estimated switching speed of less than 10 ms were used. A control unit developed over a MSP430 Microcontroller allowed the switching control and serial communication with instruments through LabVIEW. It was found that, it takes between 2 s and 3 s for high accuracy calibrators to switch between an operating DC current and an AC current, or vice versa; therefore, the current commutation time is limited by the calibrator. By using two calibrators and the implemented current switching system it was possible to reduce the commutation time to about 300 ms, which is less than the reported SJTC thermal time constant. The switching system must be fast enough to avoid the calibrators to go to a standby state. The research work showed that the switching system could be used to improve thermal converters operation for the calibration of high accuracy AC current sources and multimeters.

Keywords. Current Switching System, AC-DC Transfer Standard, Thermal Converters, SJTC

1. Introduction

To measure AC electric quantities with high accuracy it is necessary to employ AC-DC transfer standards [1]. Thermal transfer standards are based on a thermal converter (TC); its simplest form is a Single Junction Thermal Converter (SJTC), as presented in Figure 1. A SJTC is composed of a heater with a thermocouple attached to its middle point; the thermocouple is thermally coupled with the heater but electrically isolated. The operational principle of transfer standards (as shown in Figure 1) is based on thermal effects. When a known DC current flows through the heater, energy is dissipated in the form of heat and the thermocouple measures the temperature as a DC output voltage. Then, the unknown AC current is applied and the voltage response of the thermocouple is also measured as a DC voltage. If the RMS value of the signals applied is the same, the dissipated energy on the heater and the thermocouple response are expected to be the same. However, this is not the case as SJTCs don't have an ideal behaviour due to thermoelectric effects such as Peltier and Thomson heating [2]. Due to this non-ideal



behavior, TCs have to be characterized in terms of its AC-DC transfer difference and its associated uncertainty.

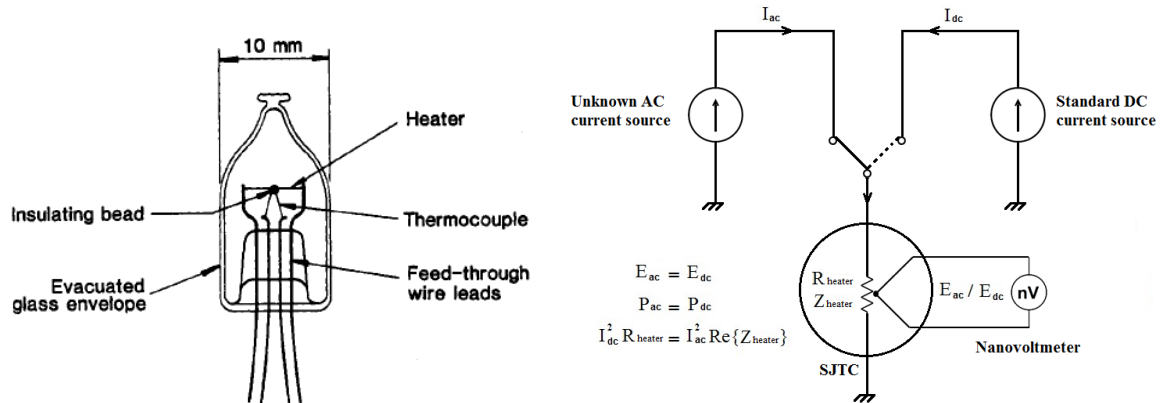


Figure 1. Left: Schematic of a Single Junction Thermal Converter (taken from [1]). Right: AC-DC Current Transfer Standard operational principle.

In AC current calibrations of high accuracy current sources by using thermal converters, it is important to guarantee a constant heating condition through the TC. This means that the switching time between the applied DC current and AC current should be sufficiently short, in this case, less than the thermal time constant of the TC [3] which is reported for SJTCs between 1 s and 4 s [4].

At INM (AC and DC current Lab) we have SJTCs as transfer standards in conjunction with current shunts to calibrate high accuracy AC current sources and 8.5 digit multimeters. In this case, the current sequence presented in (1) is used to determine the AC-DC current transfer difference of the pair SJTC-shunt.

$$I_{ac} \rightarrow I_{dc-} \rightarrow I_{ac} \rightarrow I_{dc+} \rightarrow I_{ac} \quad (1)$$

To guarantee a constant thermal condition in a SJTC, it is necessary to implement a current switching system. Most of the switching systems used in AC-DC transfer applications are designed to commute voltage [3], [5]. Even for AC current calibrations by AC-DC current transfer standards, the most common practice is to commute the voltage at the input of a transconductance amplifier to generate the required DC and AC current [6], [7].

In this study, a current switching system is proposed to directly commute AC and DC current from high accuracy calibrators. The system should be fast enough to avoid that current sources go to a standby state while the current commutation is performed, the commutation time should be less than the SJTC thermal time constant.

2. Materials and methods

A current switching system for AC-DC current transfer calibrations was designed and tested at INM. Figure 2 shows a diagram of the proposed system, which is composed of a software developed in LabVIEW and a hardware (based on a microcontroller) to control the commutation of high current and voltage latch relays. A MSP-EXP430G2 Texas Instrument LaunchPad Development Kit based on a MSP430G2553IN20 microcontroller was used to control two vacuum latch relays KILOVAC K41P334 from TE connectivity, through TIP31C power transistors. Each relay was protected with a 1N4007 diode to prevent from reversed currents. KILOVAC relays have independent inputs to open or close the latching actuator.

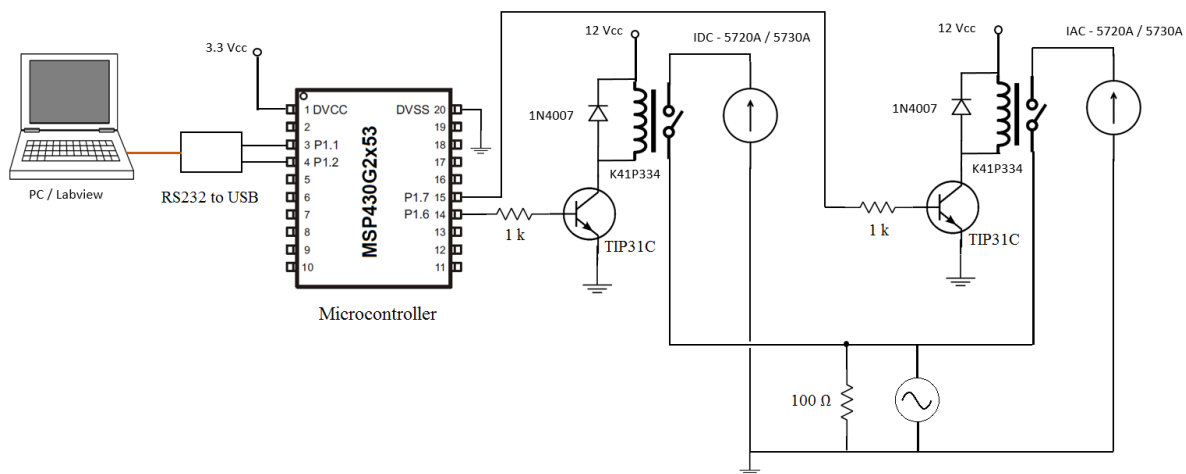


Figure 2. System diagram of the proposed current switching system for AC-DC transfer applications

The microcontroller communicates via USB with a software developed in LabVIEW 2014 which sends control signals to the microcontroller to prepare the relays for proper operation. Once the relays are ready, the microcontroller sends back control signals to the LabVIEW application to operate the high accuracy current sources in a coordinated way; these control signals avoid that both current sources operate at the same time and reduce the switching time as presented in Figure 3. In this research work, the switching system is designed to switch from a DC reference current to an unknown AC current for AC-DC Transfer calibrations of high accuracy current sources, such as calibrators Fluke 5720A and Fluke 5730A, as presented in Figure 4. The current switch should work for DC currents from 5 mA to 20 A and AC currents rated at the same values for frequencies from 40 Hz to 5 kHz.

The tests that were made to verify the switching system are described below:

- **Relay switching speed characterization:** A test was performed to measure the relay speed.
- **Calibrator operating speed characterization:** The time that a calibrator takes to go from an operating current at the output to a standby state was analysed. It was also characterized the time it takes a calibrator to change its output from an operating DC to an AC current and vice versa.
- **Commutation time reduction:** A final test was performed to verify the commutation time reduction from a DC current to an AC current by using the proposed switching system.

A two channel Analog Discovery oscilloscope from Digilent was used to measure the switching time between an AC and a DC current applied to a 100 Ω resistor. Temperature and relative humidity in the laboratory are controlled to $23\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ and $45\% \pm 15\%$ respectively, to guarantee the measurements results. Atmospheric pressure is measured with variations within $752\text{ hPa} \pm 5\text{ hPa}$.

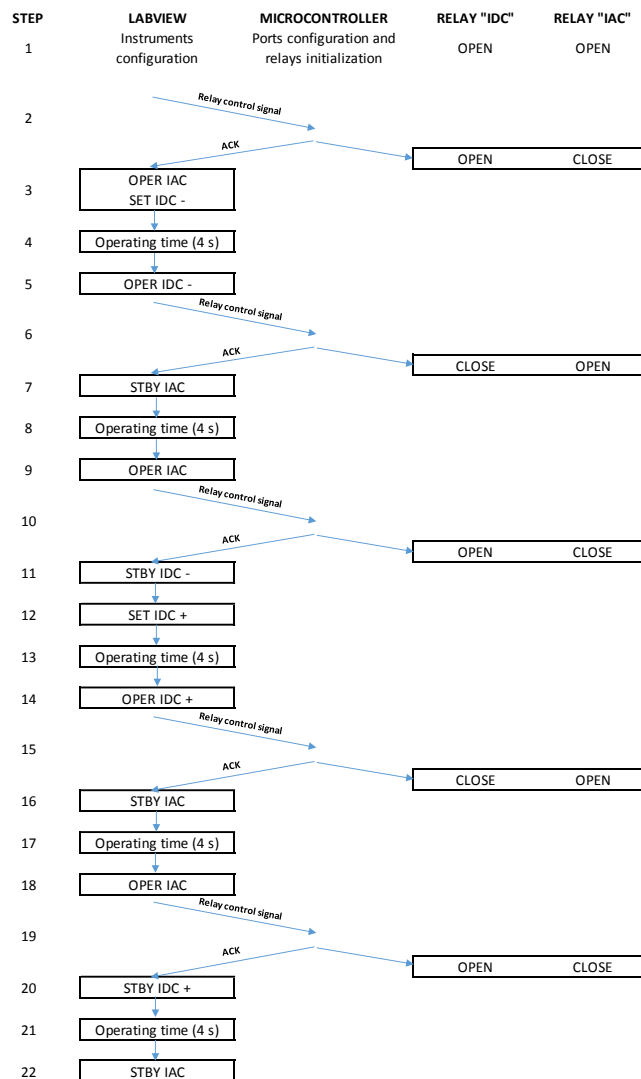


Figure 3. Flow diagram of communication between LabVIEW and the microcontroller

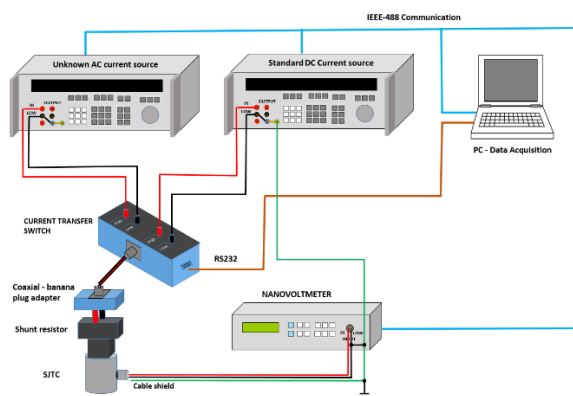


Figure 4. Left: Circuit connection for calibration of high accuracy current sources using a current switch. Right: Experimental setup to test the current switch system using a 100 Ω resistor.

3. Results and discussion

3.1. Relay switching speed characterization

For this test, we used a calibrator Fluke 5720A generating 8 V, an oscilloscope to measure voltage and the MSP-EXP430G2 LaunchPad to send the control signals to open or close the relays.

To characterize the relay speed commutation, the relay was connected at the Hi terminal of a Fluke 5720A calibrator. Then, the voltage between the relay output and the calibrator Lo terminal was measured when a control signal was applied to the relay. Figure 5 shows that it takes less than 5 ms for the relay to switch between an “open” and a “close” state.

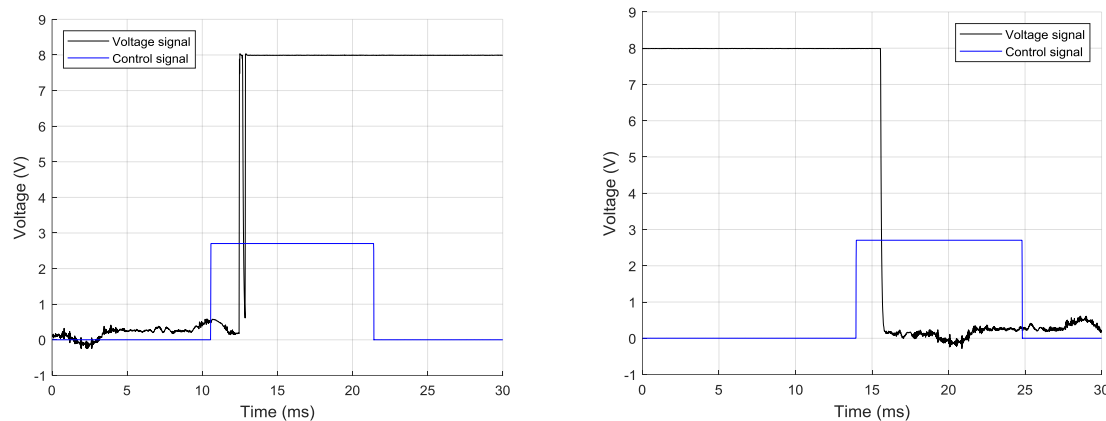


Figure 5. Relay speed commutation < 5 ms. Left: a control signal to close the relay is applied and the voltage is measured at the relay output. Right: a control signal to open the relay is applied and the voltage at the relay output goes to zero.

3.2. Calibrator operating speed characterization

When the current is switched from one source to another, there is a risk that one of the current sources goes to a standby state, if the commutation time is sufficiently long. For this reason, a test was performed to identify the minimum commutation time needed to avoid a current source from going to a standby state. For this test, a Fluke 5720A calibrator, a 100 Ω resistor, a two channel oscilloscope and the proposed current switching system were used. A 20 mA current generated by the calibrator was applied to the resistor; the relay output is connected between the calibrator and the resistor. The oscilloscope continuously acquired (at 80 kHz) both the voltage on the resistor and the control signal applied to the relay input 1 (the one used to open the relay). Figure 6 shows that when the control signal opens the relay, the current flowing through the resistor goes to zero. Then, a control re-connection signal was applied to the relay input 2 (the one used to close the relay) at different times after disconnection (0.5 s, 0.7 s and 1 s). The control re-connection signal is not displayed in Figure 6. It was found that, high accuracy calibrators are able to operate current without going to a standby state, even if the load is disconnected for less than 700 ms.

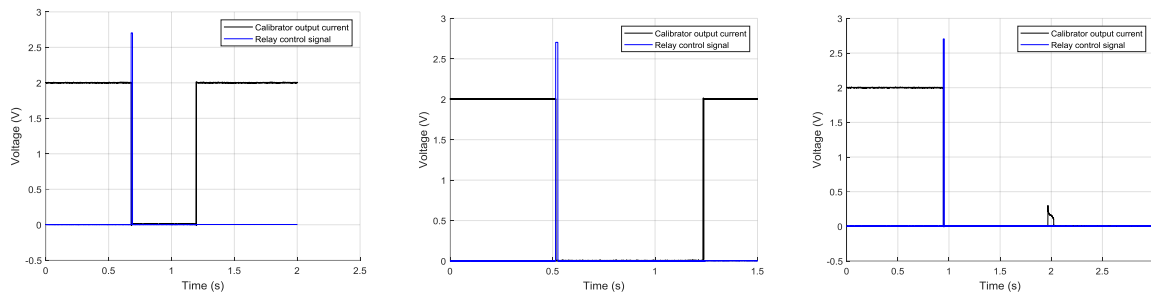


Figure 6. Disconnection time when a calibrator is operating at 20 mA (left: 0.5 s. middle: 0.7 s. right: 1 s).

A Fluke 5720A calibrator was characterized in terms of its commutation time from AC to DC current. In this case, a 20 mA / 55 Hz current was applied to a 100 Ω resistor and the voltage across the resistor was continuously acquired by an oscilloscope (at 80 kHz). Then, the operating current was changed to -20 mA by software. As shown in Figure 7 (left), the calibrator requires approximately 2 s to switch from an AC to a -DC current. The test was repeated operating the calibrator from -DC to AC current and the commutation time was about 2.5 s as shown in Figure 7 (right). Switching from -DC to AC takes more time because it requires a longer initial oscillation when operating from 0 A to the nominal current applied. It is also important to note that the AC current steady state value is obtained after 3 s.

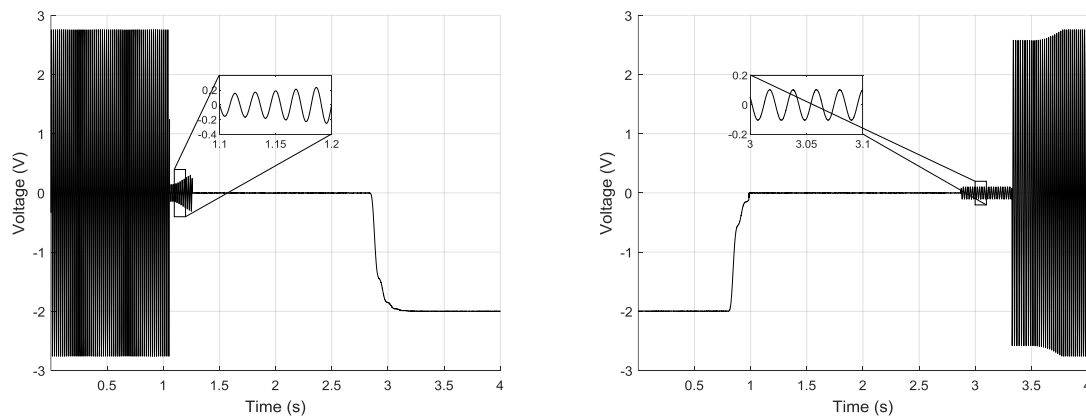


Figure 7. Commutation time from AC to -DC current (left) and from -DC to AC current (right).

It was also analysed the time it takes to the calibrator from operating from an AC current to a positive DC current and vice versa as shown in Figure 8, and the commutation time is approximately the same (> 2 s). As it was mentioned in the introduction, SJTCs have a time constant between 1 s to 4 s, so having an open circuit state longer than 2 s across its internal resistor is not desired.

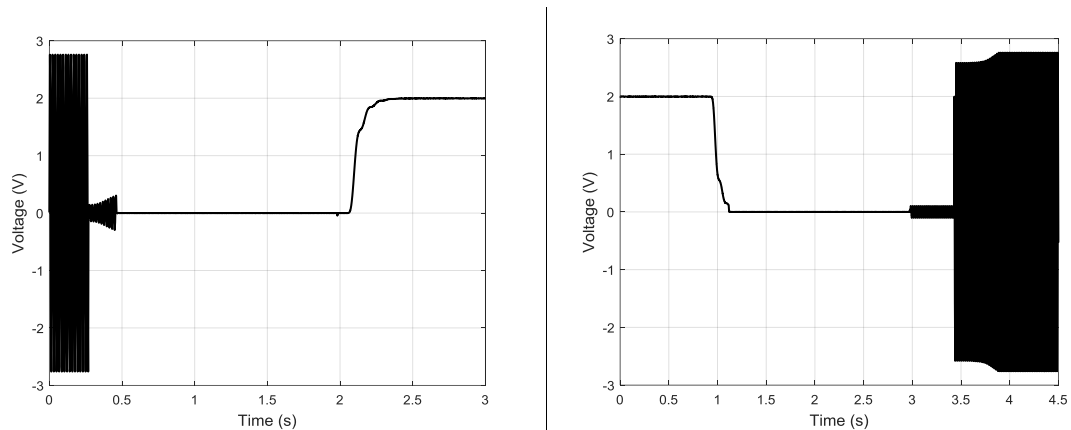


Figure 8. Commutation time from AC to DC current (left) and from DC to AC current (right).

3.3. Commutation time reduction

A sequence current with a nominal value of 20 mA at 55 Hz was applied to a 100 Ω resistor according to (1) by using a current switching system as shown in Figure 4 (right). A Fluke 5720A calibrator was used as the DC current source and a Fluke 5730A calibrator as the AC current source. The voltage across the 100 Ω resistor was continuously acquired by an oscilloscope (at 50 kHz) during the complete current sequence. The complete current sequence takes about 20 s. By using the proposed current switch with the software developed in LabVIEW it was possible to reduce the commutation time from AC to -DC current and vice versa to about 0.3 s (as shown in Figure 9) which is far less than the SJTC thermal time constant.

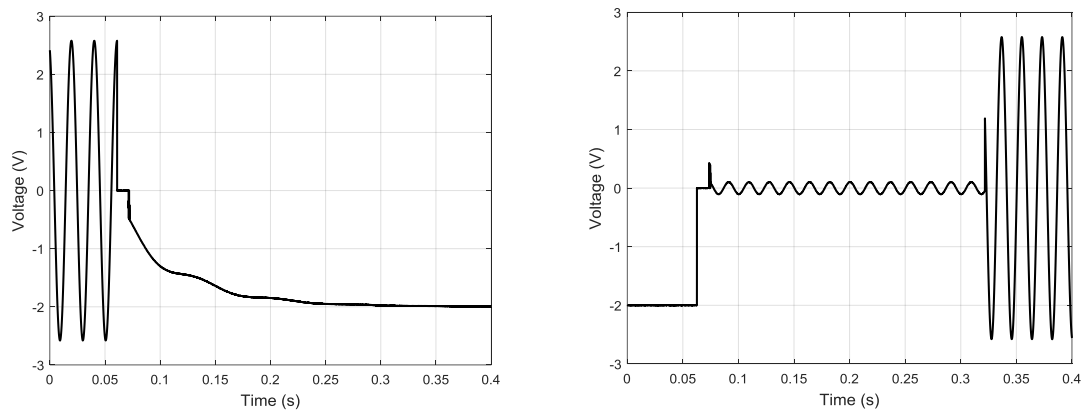


Figure 9. Optimized commutation time from an AC current to a -DC current (left) and from -DC current to an AC current (right).

The commutation time from AC to DC current was also about 0.3 s, as shown in Figure 10.

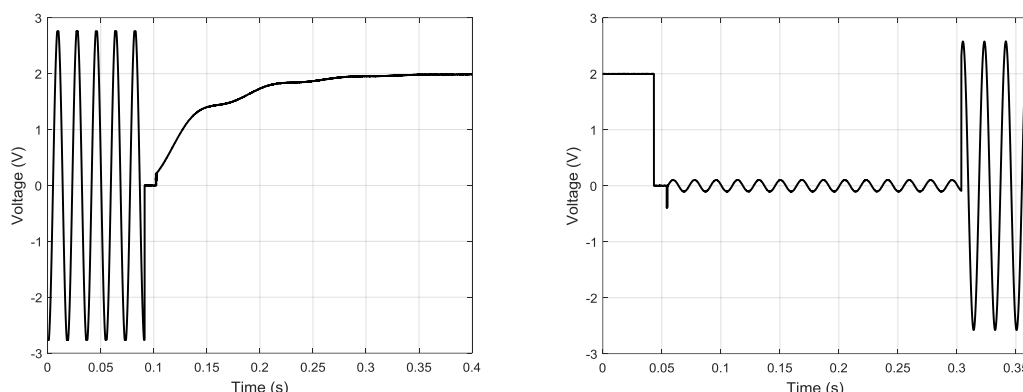


Figure 10. Optimized commutation time from AC to DC current (left) and from DC to AC current (right).

4. Conclusions

The current switching system was successfully tested. It was verified that vacuum latch relays have a response time of approximately 5 ms, which is fast enough for this application. It was found that, high accuracy calibrators are able to operate current without going to a standby state, even if the load is disconnected for less than 700 ms; taking advantage of this interesting feature along with the current switching system a reduction of the commutation time between AC and DC current and vice versa was achieved, from about 2.5 s (where the same calibrator generates the AC and DC current) to 0.3 s (where two calibrators are used in conjunction with the proposed current switching system). This system is intended to be used in calibrations of high accuracy current sources such as the Fluke 5720A and 5730A calibrators by using AC-DC current transfer standards. It is also possible to use this system for 8.5 digit multimeters AC current calibration and any other calibration based on AC-DC transfer standards.

The current switching system will improve the SJTC measurement performance. A current commutation time less than 1 s leads to a more stable SJTC thermal operation and better type A uncertainties in the AC-DC current transfer difference. As this is an initial design, further improvements could be made. It is important to design and build a single unit for all the system, with proper connectors.

It is also important to perform different tests to ensure that the currents generated by each current source will never add together (or being in parallel) as this could destroy the SJTC. Finally, it will be important to evaluate commutation time for different currents values at different frequencies.

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