COAXIAL MULTIPLEXER FOR AUTOMATIC MEASUREMENT OF AC CURRENT

Ondřej Boštík
Doctoral Degree Programme (1), FEEC BUT
E-mail: bostik@feec.vutbr.cz

Supervised by: Karel Horák
E-mail: horak@feec.vutbr.cz

Abstract: The paper presents recent work on measurement automatization at the Czech Metrology Institute (CMI) in Brno. The purpose of designed equipment is to automatically switch current shunts during the calibration procedure of precise current sources. The article presents some of the main components including voltage follower and coaxial multiplexer itself and the final solution.

Keywords: CMI, current measurement, measurement axiomatization, calibration, voltage follower, shunts switch

1 INTRODUCTION

Precise calibration of AC current supply can be very time-consuming process. Special current shunts are used to measure current indirect. Workers from Czech Metrology Institute need to change these current shunts for every measurement range manually. The goal of this work is to describe the automatic system, which switches current shunts remotely using common measuring bus GPIB. New equipment must minimally affect measured circuit, lower the phase error caused by connecting digital voltmeter to the circuit. Moreover voltage drop on the current side must not exceed 1.5 V including the connected shunt and the whole device must work with minimal noise.

Realized equipment consist of two main blocks. One is the multiplexer itself and the voltage follower, the unity gain amplifier, which lower the error caused by loading the measured circuit.

2 CURRENT SITUATION

Before this project has started, CMI workers developed two essential devices used here. Precise current shunts and GPIB Universal Interface, a proprietary unit meant to be integrated into general machines to enable them to be controlled via GPIB interface.

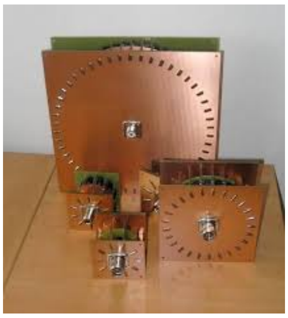

Figure 1: CMI current shunts (taken from [1])

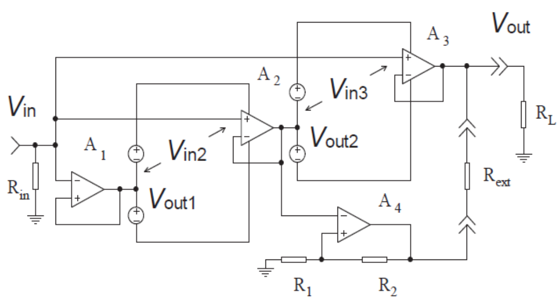

Figure 2: The principle diagram of the voltage follower (taken from [2])

2.1 CMI CURENT SHUNT DESIGN

CMI workers use current shunts of cage design (see fig. 1), which consist of parallel linked precise resistors from Vishay. The designed range various from 30 mA to 100 A, the nominal output voltage is 1 V. The frequency range of the current sources is from 10 Hz up to 100 kHz. All current shunts use coaxial connectors type N or UHF, depends on presumed current [1].

2.2 GPIB UNIVERSAL INTERFACE

This device was designed as single-board PCB which includes 16 digital inputs and 16 digital outputs, two analog outputs and four analog inputs (8bit or 16bit resolution), UART bus and SPI bus in both master or slave mode. The whole device was designed and manufactured in CMI's laboratory [3].

3 VOLTAGE FOLLOWER

The essential part of proposed device is the voltage follower. This device is essential to unload the measured circuit and lower the measurement error of connected voltmeter. Input circuits of voltmeter consist of $R = 10\ M\Omega$ and $C = 100\ pF$, which make significant phase delay of 100 μrad on 100 kHz.

3.1 INITIAL DESIGN

The design of voltage follower is based on a commonly used idea presented in the year 1999 as a part of the high-frequency thermal comparator in [4].

The main idea is to upgrade normal non-inverting unity gain amplifier with more stages which correct the error of the previous amplifier. As you can see at figure 2, the amplifier A1 utilize standard unity gain amplifier for the input voltage V_{in}. The output of this first amplifier V_{out1} is used as common ground for the second amplifier A2. This stage works only with the error voltage and its output V_{out2} copy the input voltage V_{in} more accurately. The third stage A3 is based on the same idea. If the voltage follower is meant to drive significant current, the A4 can be added to the output [2].

During simulations of the design was discovered, that optimal result shows the op-amp ADA4610 as input amplifier A1 and output amplifier A4. The reason to select this op-amp was presence of FET input stage for high input capacity. The correcting stages A2 and A3 consist of two ultra low noise op-amp ADA4899.

3.2 POWER SUPPLY

Typical operational amplifiers use symmetrical power sources. To simplify the design, the DC-DC voltage converter was used. The selected model is JCA0605D03 from the company XP Power [5], which converts $+5V\ DC$ to symmetrical voltage $\pm 15V\ DC$. The main benefit of using this voltage converter lies in the fixed working frequency of $300kHz$ independently on the current drawn. This frequency lies out of the desired frequency, furthermore, it can by simply cut off by a low-pass filter.

To smooth this power supply, the pair of linear stabilizers MC78M12 and MC79M12 was used. On the other side, this upgrade lowers the input voltage to $\pm 12V\ DC$.

3.3 ACHIEVED RESULTS

For the calibration purposes, the constructed prototype of the voltage follower was tested with DAC PC card NI PXI 6733 as a generator and the ADC conversion 24bit PC card NI PXI 5922 was used as a digital voltmeter. Sampling rates of booth PC cards were synchronized via clock output of PXI 6733 (5 MHz) to ensure coherent sampling rate.

The FFT is used to calculate the voltage vectors. Before the measurement, the transmission buffer was self-calibrated with the connected inputs A and B. The residual error of the multiplexer was then corrected during measurement. The deviations of amplitude and phase obtained by measuring the dependence of the input signal are shown in fig. 3. Associated uncertainty was determined by qualified estimates made by CMI staff.

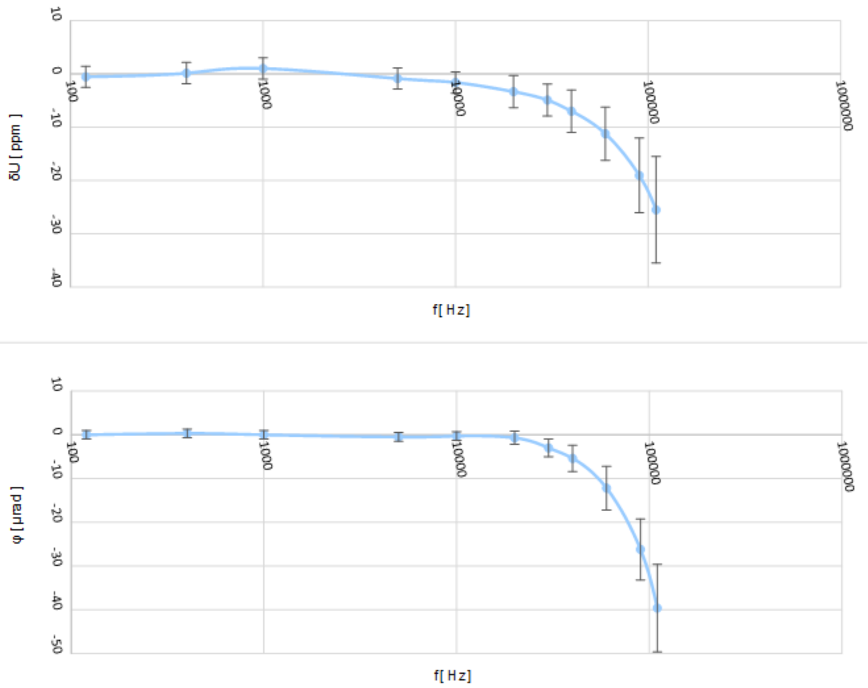

Figure 3: The dependence of amplitude and phase of the input signal obtained from the calibration voltage follower

4 COAXIAL MULTIPLEXER

The main part of introduced equipment is the coaxial multiplexer, a device capable of switching precise current shunts via GPIB. The current situation in the CMI laboratory states several demands on the final device:

- two pairs of input clamps,
- capability to connect various current shunts:
  - 6x small shunts rated for currents from 30 mA to 1 A with coaxial connector N,
  - 2x medium shunts rated for currents from 2 A to 5 A with coaxial connector N,
  - 2x big shunts rated for currents from 10 A to 20 A with coaxial connector UHF,
- detachable implementation of voltage follower,
- local and remote control,
- focus on minimizing measurement uncertainty and negative interference.

4.1 KEY COMPONENTS

One of the most significant components of introduced device are the switching elements. Many variants were considered, including switching transistors and solid-state relays. These parts can considerably affect measuring circuits. The best solution was utilized electromagnetic bistable relays, which add only small transfer resistance to the measured circuit. Also, no current is present in the relay coils after the switching is completed, so there is no current transferred to the measuring circuit via induction from the control circuit.

The most precise measurement relays are manufactured by company Omron [6]. These relays can be found as part of the measurement devices from companies like Keysight Technologies. For the small currents up to 1 A the most optimal solution is SMD mounted relay OMRON G6SU-2G rated for 2 A. Manufacturer states recommended applications like measurement devices and Hi-fi [6]. The medium shunts are switched via bistable relay OMRON G5RLK1-E rated for up to 16 A [6].

For the biggest currents and input clamps switching, the bistable relays cannot be utilized. The choice was made to use relay OMRON G8P-1C4TP [6]. Usage of the monostable relay has also the advantage in security because during power or control circuit failure the relays go to the safe position.

The second significant type of components are the coaxial connectors. For the N-type the RADIALL R161441000 used and for the UHF-type, the choice was made to implement Huber&Suhner type 23_UHF-0-0-2033. These parts were chosen by CMI workers based on the long term experience.

The control circuits are built around micro-controller ATmega328P. The bistable relays are driven with integrated circuit MAX4820 used according to application note [7].

4.2 Circuits

Schematic diagram of realized coaxial multiplexer is shown in fig. 4. Typical current sources usually have two individual output clamps. The first relay pair switch between these clamps. The next relay in the circuit are included for the security reasons - it shorts the circuits when failure and forces the current sources to engage internal protection.

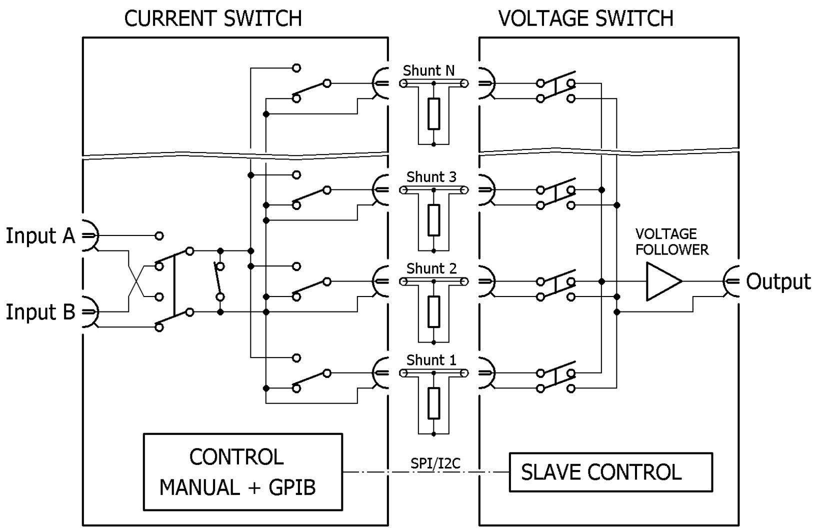

Figure 4: Schematic diagram of coaxial multiplexer

The main reason for the multiplexer is to switch between the current shunts. After the safety section, there are switching relays. The control circuit is programmed so only one relay is opened and the remaining relays are closed. To minimize the capacitive coupling, the closed relays shorts the corresponding current shunt. To limit the voltage drop by half, corresponding terminals of every double relay are connected.

The output voltage from the shunts is then conducted through another set of bistable relays. The voltage than can be routed through discusses voltage follower and carry on to the connected voltmeter.

4.3 RESULTS OF IMPLEMENTATION

Final solution is captured on fig. 5. The entire product was divided into two parts. The bigger one contains current switching unit, GPIB Universal Interface, manual control interface and main control unit. Reason to produce separate units was to minimize interference. The smaller unit contains voltage switch and voltage follower. Both units are linked via SPI.

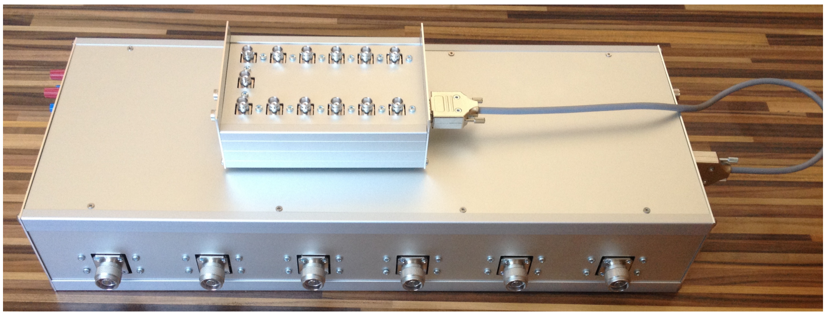

Figure 5: The realized multiplexer captured from the right side of the device

5 CONCLUSION

Article presents precise coaxial multiplexer for the purposes of the Czech Metrology Institute. The machine is capable of switching between two pairs of input clamps, ten different current shunts, engage protective relays. All the features can be operated remotely via GPIB or locally on the situation.

Important part of the device is voltage follower which lower the phase error caused by connected voltmeter.

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REFERENCES

[1] V. Nováková Zachovalová, *Accurate AC currents measurements*. Doctoral thesis, Brno university of technology. Faculty of electrical engineering and communication, Brno, 2013. [Online; accessed 14. 3. 2017].

[2] I. Budovsky and T. Hagen, “A precision buffer amplifier for low-frequency metrology applications,” in *Precision Electromagnetic Measurements (CPEM), 2010 Conference on*, pp. 28–29, IEEE Publishing, 2010.

[3] CMI employes, “GPIB universal interface,” tech. rep., CMI, Brno, 2014.

[4] I. Budovsky, A. Gibbes, and D. Arthur, “A high-frequency thermal power comparator,” *Instrumentation and Measurement, IEEE Transactions on*, vol. 48, no. 2, pp. 427–430, 1999.

[5] XP Power employes, “Jca0605d03,” tech. rep. [Online; acessed 14. 3. 2017].

[6] Omron employees, “Product catalog - relay,” 2016. [Online; accessed 14. 3. 2017].

[7] Maxim Integrated employes, “Application note 3288: Ic drives up to four single-coil latching relays,” tech. rep. [Online; acessed 14. 3. 2017].