# A Modular USB 2.0 Digitizer for Electrical Power Measurements

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***Abstract* — A metrology grade digitizer aimed for electrical power and power quality measurements is presented. The digitizer has seven simultaneously sampling floating analog-to-digital converter channels and a modular structure. Each channel has a temperature stabilized precision voltage reference, which enables future application of the system on demanding AC metrology applications. All signal processing is running on a PC, which connects to the digitizer via USB 2.0. The device and analysis software are made in-house.**

***Index Terms* — Metrology, digitizer, three-phase power, electrical grid, power quality**

## I. INTRODUCTION

Digitized measurements are becoming more common in all low frequency AC metrology, including electrical power measurement. Previously used thermal converters are impaired by their inability to extract phase information from voltage and current signals and consequently have no concept of apparent or reactive power. Digitized waveforms, however, can be used for extensive numerical analysis to obtain values for many properties of the measured power. Many NMIs have built their own sampling standards for three-phase power, based either on existing hardware [1] or designed completely for the purpose in-house [2].

The benefit of building a custom power meter is having full control of all aspects of the measurement. This paper presents a USB 2.0 enabled digitizer intended for power and power quality measurements in the electrical grid. The aim of the design is a bandwidth of 100 kHz. The target uncertainty at 50 Hz is below 1 µV/V amplitude and 1 µrad in phase between any two channels. This calls for great care in component selection and electrical design. The critical parts of the design are covered in this abstract.

## II. ELECTRICAL DESIGN

The digitizer is built inside a 19” rack case. All signaling and power supplies inside the case are routed in a backplane, which has 12 slots for peripheral cards. Seven of the slots are dedicated to analog-to-digital converter modules.

### *A. Analog-to-Digital Converters*

The choice of analog-to-digital converter (ADC) chip is steered by three major performance metrics. Firstly, it needs to be fast enough to enable a 100-kHz bandwidth. Secondly, temperature drifts should be as small as possible to facilitate also accurate field work. And thirdly, it needs to be linear in order to faithfully reproduce measured waveforms. Analog

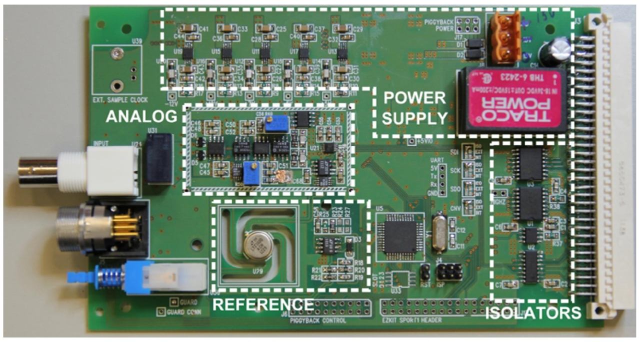


Fig. 1. A Photograph of an analog-to-digital converter card.

Devices’ successive approximation register based AD7690, a 400-kSPS, 18-bit converter was chosen. The photograph of a converter card is shown in Fig. 1. Digital isolators on the right facilitate the floating input of each converter card. Similarly, the power supply is isolated by a DC-DC converter. A two stage LC-filter is used for removing switching transients from the supply, followed by fast point-of-load linear regulators.

The most critical part besides the ADC is the full-scale voltage reference, which needs to complement the converters drift properties. Many solder-and-forget bandgap references have typical temperature drifts an order of magnitude larger than AD7690 and significant long term instability, which would require calibrating the digitizer often. Instead, Linear Technologies’ buried Zener reference LTZ1000 is used. It requires some additional, well-chosen components as well as careful PCB design to meet its specified temperature drift of 0.05 µV/V/K. Manufacturer-claimed noise output and long-term stability are also excellent. The Zener is ovenized in order to maintain an ambient-independent chip temperature. It was chosen to run the chip at 50 ºC. This limits maximum ambient operating temperature to around 30 ºC, since the chip should run at least 20 degrees above ambient. According to [3], a reasonably low operating temperature will also reduce aging rate of the reference. The 7.2-volt output of the reference is divided to 5.0 volts by a resistor network capable of $0.2\cdot10^{-6}$ /K typical ratio tracking, and then buffered by a low-drift operational amplifier to provide reference voltage for the ADC. Similar circuitry is used to set DC bias levels in the analog front end.

The single-ended ±10-volt signal input of the converter card is buffered by a voltage follower. In order to achieve high input impedance, a voltage-replica of the input is used for shielding all sensitive input routing from the input connector to the voltage follower input. A low-thermal voltage relay is

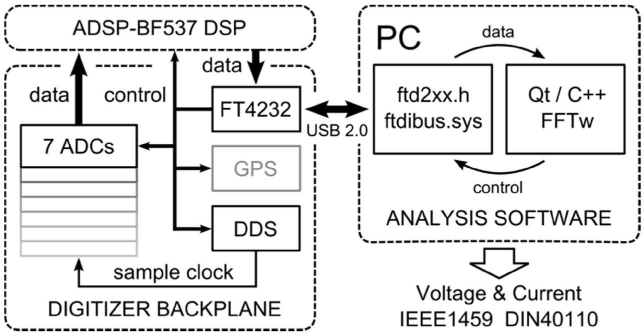


Fig. 2. Digitizer top level structure, internal data connections and external connectivity to analysis software.

placed in the input to be able to ground input at will for offset compensation. Buffered input signal is then attenuated by a factor of four and converted to differential mode to drive the ADCs input. A $0.05 \cdot 10^{-6}$ /K ratio tracking resistor network is used in the attenuator.

### *B. Sample Clock*

In order to create a flexible sample clock, direct digital synthesis (DDS) approach was chosen. Either on-board or external 10-MHz reference can be used to derive a sample clock with a high frequency resolution and good jitter properties. A 28-bit chip in the DDS module allows for 37 mHz frequency resolution for the sample clock. Changing clock resolution in the future can be done by updating to a chip with a wider frequency register. A provision for GPS module has been designed into the system for time stamping samples and to enable precise synchronization on the field.

### *C. Top-Level Design and Data Connections*

Fig. 2 shows the top level data connections of the system. The digitizer is controlled by a commercial digital signal processor card (DSP). The processor has sufficient connectivity and is fast enough to manage data flow within the digitizer. Some additional hard logic is required to connect and synchronize the DSP input-output pins to the peripheral slots in the backplane.

The DSP processor maintains on-board data buffers. The buffers are uploaded to measurement PC via USB 2.0 connection. A constant data stream is utilized, with dummy data padded into the stream for low sampling rates. A data rate of 25 Mbit/s can be achieved for each of the two channels of the converter module, and roughly double that when both channels are used simultaneously.

For fast data throughput leaving no samples unprocessed it is convenient to run the analyses in a compiled executable format. Analysis software is thus written in C++ under the open source Qt framework. The software runs in a few separate threads to optimize execution of important tasks, such as data transfer from the digitizer and processing of samples. At the moment the software calculates three-phase powers according to IEEE 1459 and DIN 40110 as well as displays the waveforms and spectra.

## III. MEASUREMENT RESULTS

During the writing of this abstract the characterization of the digitizer is still largely unfinished. Some conservative indication of the achieved accuracy is available though. Overall temperature coefficient of the analog-to-digital converter card is measured to be less than $1 \cdot 10^{-6}$ /K around room temperature. Gain flatness is better than 0.05 % up to 10 kHz. Input resistance is >10 GΩ and input capacitance 8 pF, owing mostly to the input BNC connector. The analysis software runs on an Intel Core i7 quad core processor and indications are that gapless processing of several simultaneous analyses will be possible at the targeted 200 kSPS on all 7 channels.

## IV. CONCLUSIONS

A modular seven-channel digitizer for metrology purposes has been designed and built. Preliminary measurements hint that careful analog design enables measurement uncertainty on or below the $10^{-6}$ level. Versatile synchronization and timing of the simultaneous sampling make it possible to apply the system to a variety of demanding AC metrology tasks. The development and characterization of the digitizer is still on-going.


## ACKNOWLEDGEMENT

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