Implementation of Vibration Signals Receiving Unit on Raspberry Single-Board Computers

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***Abstract*—The paper dedicated to vibration measurement system development on the Raspberry Pi basis. Main features of the solution are low-cost, easy access to components and functionality and flexibility provided by Raspberry Pi usage. Circuit solution and configuring procedures are presented and described. In particular, block diagram of the vibration measurement system with piezo-electric sensors. Two variants of the vibration measurement system, on the Raspberry Pi B+ and Raspberry Pi 3B correspondingly, were implemented and tested as well. In addition, two variants of impedance-matching device were implemented. Conducted and described experiments confirm performance both separate components and the whole solution. Presented results are applicable for correlation leak detectors new algorithmic solutions and in educational process.**

***Keywords*—vibration measurement, Raspberry Pi, ADC, audio recording, impedance-matching**

I. Introduction

The main trend in modern instrument manufacturing is microprocessor devices usage as for different signal processing algorithms as for diagnostic purposes.

Implemented algorithms determine operability and performance of microprocessor units generally [1].

Nowadays, new algorithms development and testing are main trend in the field of advanced facilities of technical diagnostics. New algorithms testing requires hardware and software solutions application for signal processing [2, 3, 4]. These solutions are applicable in educational process as a part of software-oriented education of engineers [5, 6].

In this paper vibration measurement system implementation on the low-cost Raspberry Pi computer basis. Developed solutions are used for time-delay estimation algorithms testing. The algorithms are used in leak detection correlation devices software, described in [6, 7].

II. Components and Computers

A. Concept of the Solution

The solution comprises four interconnected blocks: vibroacoustic sensors, interface module, ADC and single-board computer. Structural diagram of the solution depicted in Fig. 1.

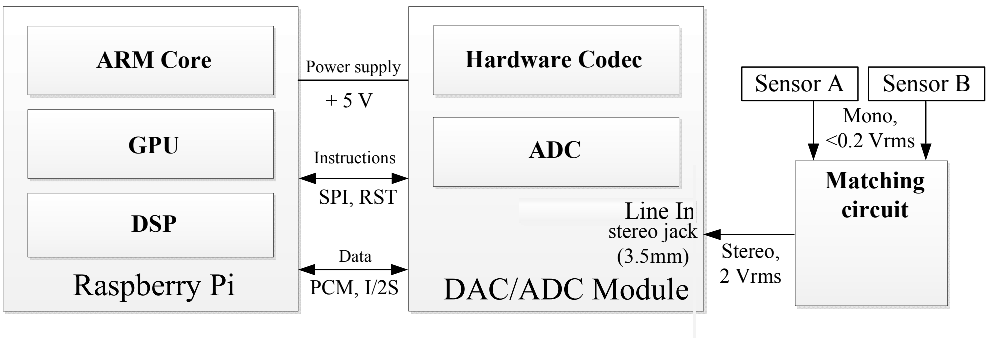

Fig. 1. Structural diagram of Raspberry based receivier for vibration signals

Interface module task is analog sensors output and ADC input impedance and level matching. Single-board computer that calculates and processes the data controls ADC.

B. Vibroacoustic Sensors

Piezo-electric accelerometers are used as a vibroacoustic sensors.

Presented devices has the following features: low level of output voltage, that proportional to vibro acceleration of the oscillating object; sensor output circuit impedance influence on precision and frequency measurement range [8].

In the research accelerometers DN-3 and DN-4 [9] are used.

C. Raspberry Pi B+

According to Fig. 1, Raspberry Pi B+ and compatible Wolfson audio card is used for receiving, discretization and collecting signal records in stereo format [10]. Despite the presented devices are assumed to be obsolete and are not

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manufactured nowadays, they are still applicable for signal processing problem. In particular, in [12] said that Raspberry Pi B+ is powerful enough for time-delay estimation problem in real-time.

D. Raspberry Pi 3B

Alternative version of signal receiver implemented on the most-recent Raspberry Pi 3B+ basis [13]. The most significant feature is almost three times more powerful CPU in comparison to Raspberry Pi B+ [14]. HiFiberry DAC+ ADC module [15] is used for signal discretization.

III. Impedance and Level Matching Circuit

Necessary condition for proper signal receiving is output circuit level and impedance matching with ADC. According to sensors specification [9], in order to fix the lower bound of frequency range at level of tens of Herz, it is necessary for input impedance to be not less than 100 kOhm with input capacitance about 1µF.

Since sensors have different sensitivity and thus provide different level of output voltage, matching device gain has to be adjustable in wide range. As a result two devices were developed. Circuits of the devices are shown in Fig. 4.

A. Matching circuit without filtering

Matching devices are constructed on the basis of the cascade of two serial-connected instrumentation and differential amplifiers. Instrumentational amplifiers application is native to measurement systems since it combines differential amplifiers advantages (high input impedance, coherent noise rejection) but it has stable gain value with low level of self noise [16].

Output amplifier provides necessary level of differential input impedance 200 kOhm with 1 µF capacitance. That yields that $f_{\min} = 7 Hz$ according to [9]

$$f_{\min} = \frac{0.79\left(R_S + R_3\right)}{R_S \cdot R_3\left(C_S + C_2\right)}, \quad (1)$$

where R_S – sensor insulation resistance (10 GOhm); C_S – sensor self capacitance with cable (2000 pF).

The second amplifier comprises dimmer for gain adjusting in the range from 1 to 3, in order to work with both DN-3 and DN-4 sensors. The output of the circuit supplied with Zener diode based limiter for avoiding ADC failure [17].

B. Matching circuit with low-pass filtering

The second circuit differ from the first by low-pass filter with cutoff frequency $f_c = 50\ Hz$

$$f_c = \frac{1}{2\pi\left(R_3 + R_4\right)C_2} \quad (2)$$

The filter reduces electric pickups influence [18]. Although, low-pass filter, according to (1), increase $f_{\min}$ value to $f_{\min} = 577$ Hz, experiment shows operability of the device with frequencies from 100 Hz.

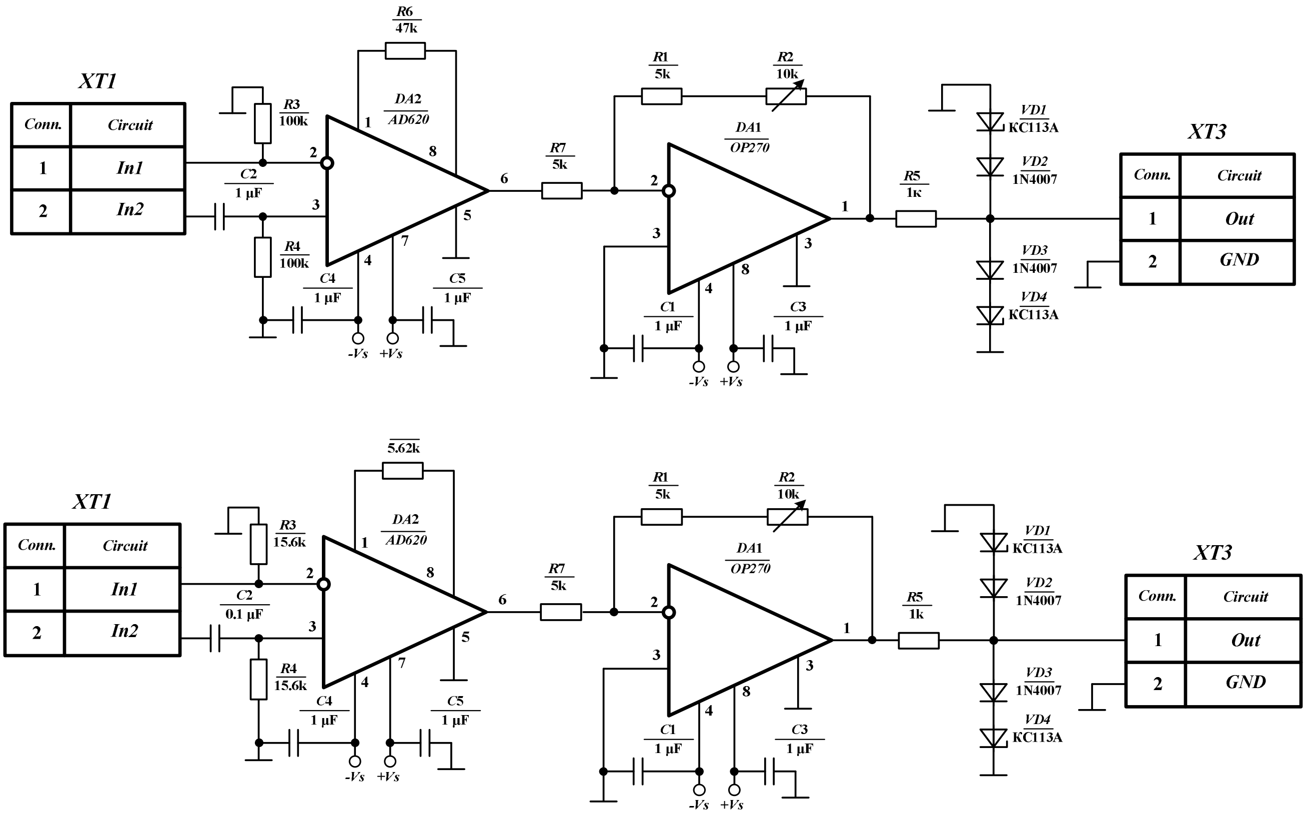


Fig. 2. Electrical circuits of the mathcing devices variants (in the top – the one without filtering, in the bottom – the one with low-pass filtering).

IV. Implementation of the Receiving Unit

As well as aforementioned hardware software essential. Since the research conducted in Raspberry Pi basis oriented way, software development comes down to single-board computer configuration.

A. Raspberry Pi B+ configuring

Single-board computer Raspberry Pi B+ with mounted Wolfson audio card configuring process includes the following steps: driver installation, record and playback interface choice and record format setting. In order to provide proper interfacing between Raspberry and audio card, the driver installation should be performed using "apt-get" utility for UNIX-based operating systems. The next step is record device choice. Since Wolfson audio card has several onboard interfaces such as Sony/Philips Digital Interface (SPDIF), digital microphones, etc. In the research 3.5 Line in connector is used and is activated via running Bash script "Record_from_lineIn.sh". The final step is proper recording. In order to get record with required quality and properties, one has to form terminal command of the following format:

"arecord –c 2 –f S16_LE –r 44100 <filename.wav>"

where –c defines number of channels, in our case 2, –f defines recording format (16-bit, Little Endian) and –r defines sample rate.

B. Raspberry Pi 3B+ configuring

Since both Raspberry Pi B+ and Raspberry Pi 3B+ use the same UNIX-based operating system Raspbian Jessie, configuring process comprises almost the same steps as a Raspberry Pi B+. The main difference is that Hifiberry allows users to adjust inner gain value for input signal with hardware onboard jumpers. Possible values are 0dB, 12dB and 32db. For the experiment, 0 dB value was chosen in order not to inject additional disturbances.

C. Interfaces and wires

Stereo jack 3.5 mm was chosen as a connectors in order to simplify wiring and experiment conduction. Mono signals channels were soldered with each other.

System shown in Fig. 5. The second variant of matching device was implemented in metal case for electromagnetic pickups reduction.

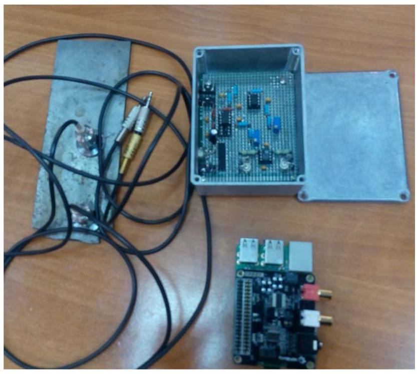


Fig. 3. Vibration signals receiveing unit on Rapberry Pi 3B+

V. Operability Test

Experiment was conducted in laboratory conditions. Experiment includes receiving two time-shifted copies of vibroacoustic signals. Through stereo amplifier, PC-plugged vibrodynamics utilized as a playback device. More detailed experiment description presented in [19]. Experimental setup shown in Fig. 6.

In Fig. 7 actual and reference signals spectrum characteristics are depicted. Spectrum difference is due to non-homogeneous surface where sensors and dynamics were positioned and time-delay between channel as well.

During the experiment it was discovered that time-delay estimation can be perform using received vibroacoustic signal copies. Time-delay estimation precision is 0.5 ms (1.5% of relative length of correlation function time scale, shown in Fig. 7). This fact allows system to be utilized for leak detectors software testing in laboratory conditions [3].

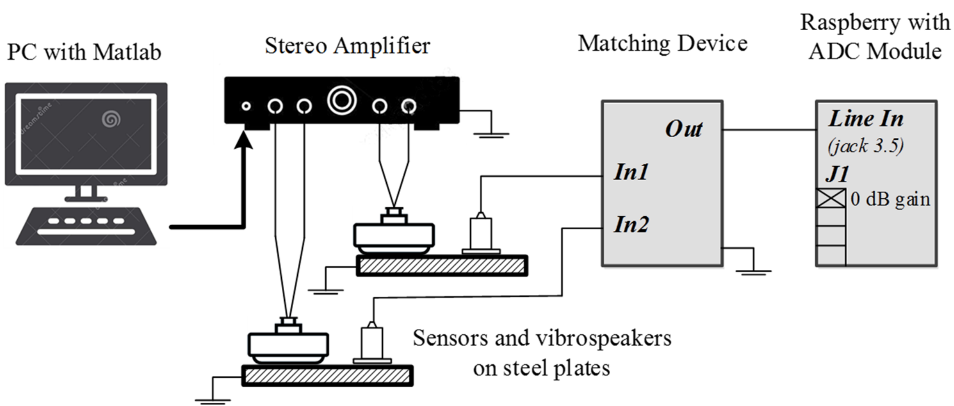
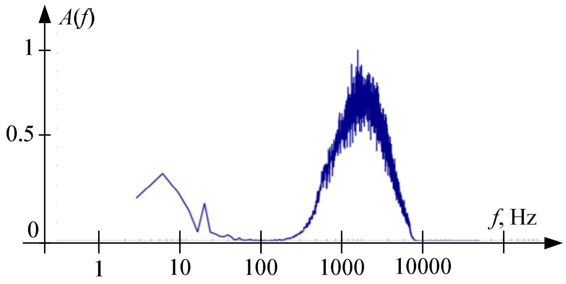
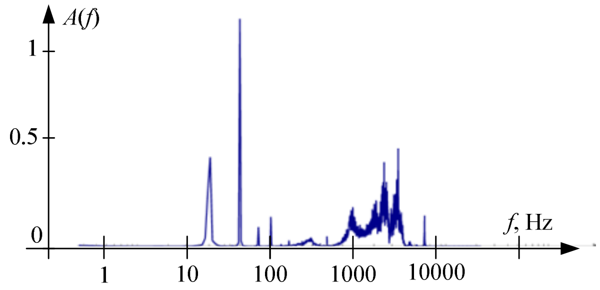


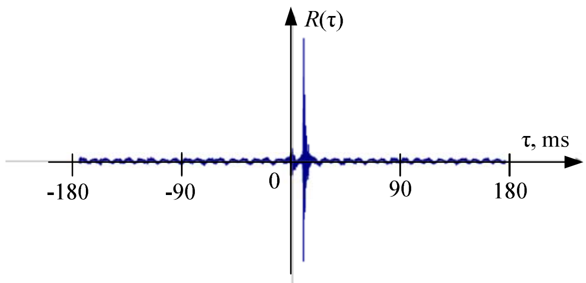
Fig. 4. Experimental setup



a)



b)



c)

Fig. 5. Specters of the a) power cross spectrum of the reference signal; b) power cross spectrum of the recieved signal; c) cross-correlation between channels of the received signals.

VI. Conclusion

Developed and tested vibroacoustic signals processing on the Raspberry Pi single-board computer basis device is properly functioning and applicable as for research leak detector model as for educational purposes. One of the main advantages of Raspberry Pi-based solutions is high-performance (Raspberry Pi 3B+ in particular). It allows not only performing software signal processing including electrical pickup reducing, but also time-delay estimation in real-time scale.

The next step of the development is deploying software algorithms directly on single-board computers and their performance research. It gives the opportunity to get correlation leak finder functioning prototype that can be used with pipe virtual model and in field conditions as well.

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