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IMPLEMENTATION OF A LOW COST REMOTE FAILURE MONITORING SYSTEM FOR SPEAKER LINES IN A SHOPPING MALL

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Nowadays, Public Address (PA) designs are primarily used for background music and evacuation messages broadcast during emergencies. For the latter, it is very important to detect if there is a partial failure, disconnection or short circuit in the speaker lines. In this work, a very low cost remote failure monitoring system for speaker lines is presented in detail. A relay array, controlled by a Raspberry Pi computer, is in charge of switching between the different lines. Each line is measured with test signals between 80 Hz and 10 kHz. Finally, the information is sent to a cloud-database. The final user can access to it through a web interface, and receive alerts if a failure is detected. The results from a shopping mall's PA system monitoring are presented.
Keywords: Electroacoustic, failure, monitoring, loudspeaker

1. Introduction

Audio designs have evolved, from simple background music to evacuation and voice alarm systems. This requires an increase in the reliability of the project, and a change in the way the industry sees installed sound. The term Public Address (PA) can be used to include all sound systems in airports, railway stations, shopping and leisure centres, stadia, industrial complexes and public buildings where paging, general and emergency announcements, are broadcasted [1]. A failure in a loudspeaker line when an evacuation message is being voiced can be very critical. In this work, a low cost PA failure monitoring system is presented, which can be remotely administrated through a web interface.

The system takes the measurement disconnecting the loudspeaker line from its respective amplifier only few seconds. Later, the information gathered is uploaded to a web database. The brain of the system is a Raspberry Pi (RPI) computer, a small but powerful device that runs a Linux based Operating System (OS). It has internet connection and is capable to communicate with several external hardware parts through GPIO pins [2]. The system is designed to have a minimal error, but still is able to recognize the three typical failures: short circuit (theoric zero electrical impedance), open circuit (theoric infinite electrical impedance) or big impedance change (partial failure). Implementation of testing systems for distributed audio loudspeaker lines can be found in the literature [3]. In Section 2 a detail of the system hardware and software configuration is presented, in Section 3 the results of a reference and shopping mall speaker lines measurement, and finally, Section 4 shows conclusions and remarks.

1.1 Background

The loudspeaker electrical impedance is affected by the electro-mechanic transducer, the movement of the mechanics elements and the air load on the diaphragm [4]. The expression for the electric impedance Z_{EE} of a loudspeaker is detailed in Eq. (1):

$$\boldsymbol{Z_{EE} = R_E + j\omega L_E + \frac{(Bl)^2}{\omega_s} \frac{\frac{1}{Q_{MS}}\left(\frac{j\omega}{\omega_s}\right)}{\left(\frac{j\omega}{\omega_s}\right)^2 + \frac{1}{Q_{MS}}\left(\frac{j\omega}{\omega_s}\right) + 1}} \quad (1)$$

Where j is the imaginary number, R_E is the purely electrical impedance of the voice coil, ω is the angular frequency, ω_s is the angular frequency of resonance, L_E is the electrical inductance of the voice coil, B is the magnetic flux density of the magnet, l is the length of the voice coil, R_{MS} is the mechanical resistance of the suspension and Q_{MS} is the quality factor of the loudspeaker.

The nominal impedance Z_n is the minimum value after the resonance. Is often used for design, as it represents the frequency where the amplifier will deliver greater intensity. When the impedance of a loudspeaker is measured in an acoustic enclosure, ω_s will tend to increase, among other things, because the radiation impedance is modified.

For the specific case of audio electronics, a transformer must be capable to transmit current in a wide frequency range [5]. Depending on the ratio of turns in the windings of the transformer, it can step up or step down the current. As a transformer is usually connected between two terminals with different impedances, it acts as a coupler and can be used as a voltage multiplier or divider. The impedance ratio between the two ends of a transformer is in function of the winding ratio of the terminals, and is determinate by Eq. (2), where Z_1 and Z_2 are the terminals impedances. N_1 and N_2 are the number of turns in the two windings.

$$\boldsymbol{Z_1/Z_2 = \left(N_1/N_2\right)^2} \quad (2)$$

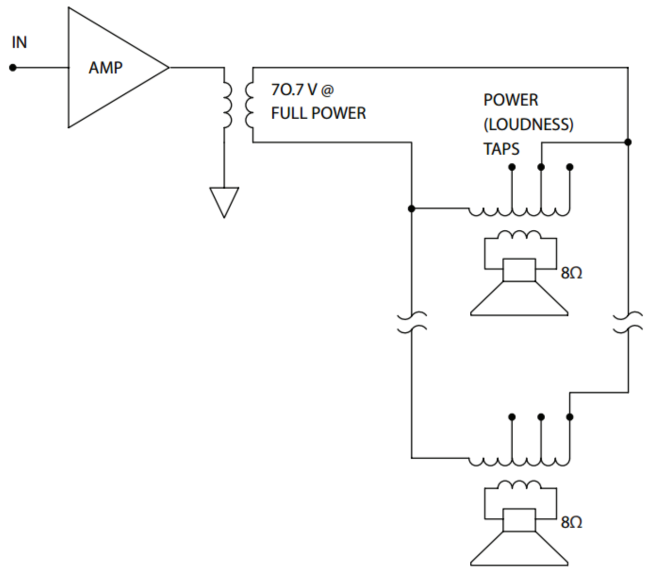

Figure 1: Amplifier and speaker connection using transformers in a constant voltage audio system (1997 Rane Corporation).

Constant voltage audio distribution systems were developed to minimize cost, stepping up the voltage in order to step down the current. This allows the use of smaller cables [6]. The output of the distribution amplifier is feed to a transformer that raises the full power voltage to 70.7 V (or 100 V).

Every loudspeaker in the distribution line has a step down transformer, which drops down the voltage and increases the current of the signal to drive the low impedance (4 to 8 Ω) loudspeakers. To a better distribution of the energy, the loudspeakers have different power taps, so different areas can have more or less loudness level depending on their use.

2. System configuration

2.1 Hardware and software

The entire system is built around a RPI. This credit-card sized computer was born in the Computer Laboratory in Cambridge University, leaded by Eben Upton [7]. As peripherals, an analog to digital converter (ADC) is used to take the voltage measurements [8]. The test signal provided by the RPI was conditioned with an audio amplifier [9]. To increase the number of lines that can be measured, a relay array in addition to an input-output expander was used [10].

The RPI can run a long list of OS [7]. The chosen one was Raspbian, a Debian based distribution designed especially for the RPI. The development of the script to communicate all the hardware was written in C, a general-purpose procedural programming language, devised by Dennis Ritchie in the 1970s at AT&T Bell Laboratories [11]. One of the main advantages of using C is the GCC compiler. It was developed by Richard Stallman for the GNU Project [12]. The GCC compiler works great with the extensive standard C library, third party libraries and comes pre-installed in Raspbian.

2.2 Interconnections

The system is connected according to the Fig. 2. The line selector is a relay array with the input-output expander as the master, controlled by the RPI through the I2C port. Once a line is selected for measuring, the RPI sends test tones by the provided audio out between 80 Hz and 10 kHz in the centre frequency of the third octave bands. The signal pass through the amplifier and measurements are taken before and after a reference resistor by the ADC, which is managed by the RPI thought the SPI port. All this information is packaged in a string and is sent to the cloud database to be stored and later managed via the web interface.

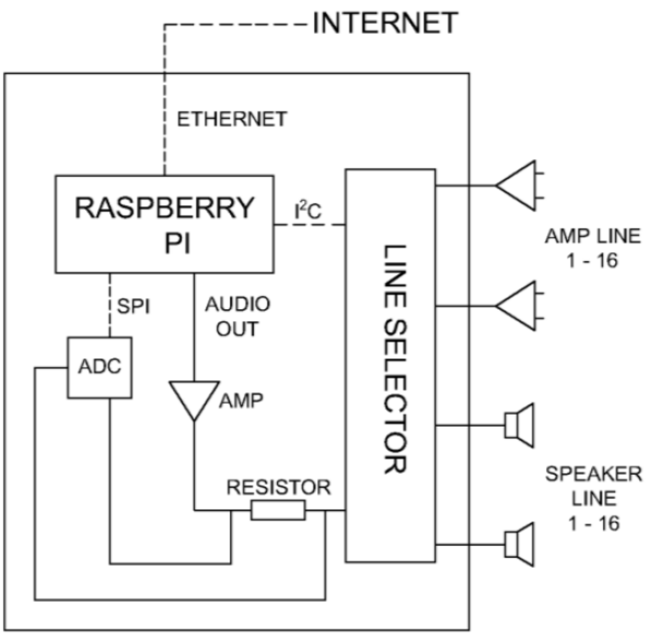

Figure 2: Layout of the hardware interconnections and software controls.

3. Results

3.1 Reference line measurement

The system was first tested with a reference line of speakers. Table 1 and Fig. 3 shows the values obtained and the analysis of the data. The nominal impedance Z_n is taken as the minimum value in the band between 315 Hz and 1 kHz for the reference, and later taken in the same frequency for each scenario. The value ΔZ_n is the absolute value of the difference between Z_n in each scenario and the reference.

Table 1: Values of the reference line measurement under different conditions

Measurement	Z_n Frequency (Hz)	Z_n	ΔZ_n
Reference	315	157.59	--
Short circuit		9.82	147.77
Open circuit		539.84	382.25
Big impedance change		354.40	196.81

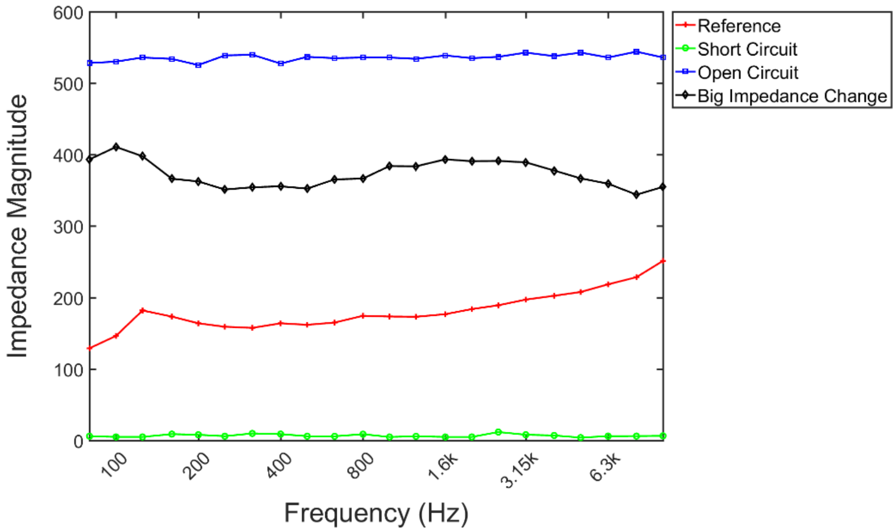

Figure 3: Measurements of the reference line under different conditions.

3.2 Results in the shopping mall

The results for 3 weeks of monitoring 4 loudspeaker lines in a shopping mall are presented in Fig. 4. The values obtained of the analysis of the data are presented in Table 2. A single measurement was taken at 3 AM every day. The values Z_n and ΔZ_n are calculated the same way as the reference line measurement, taken the first measurement as reference representing the line in normal operation.

Table 2: Values of the shopping mall lines measurements.

Line	Measurement	Z_n Frequency (Hz)	Z_n	ΔZ_n Max
1	21	315	24.01	17.88
2		400	21.52	14.98
3		800	46.90	9.98
4		400	177.38	13.43

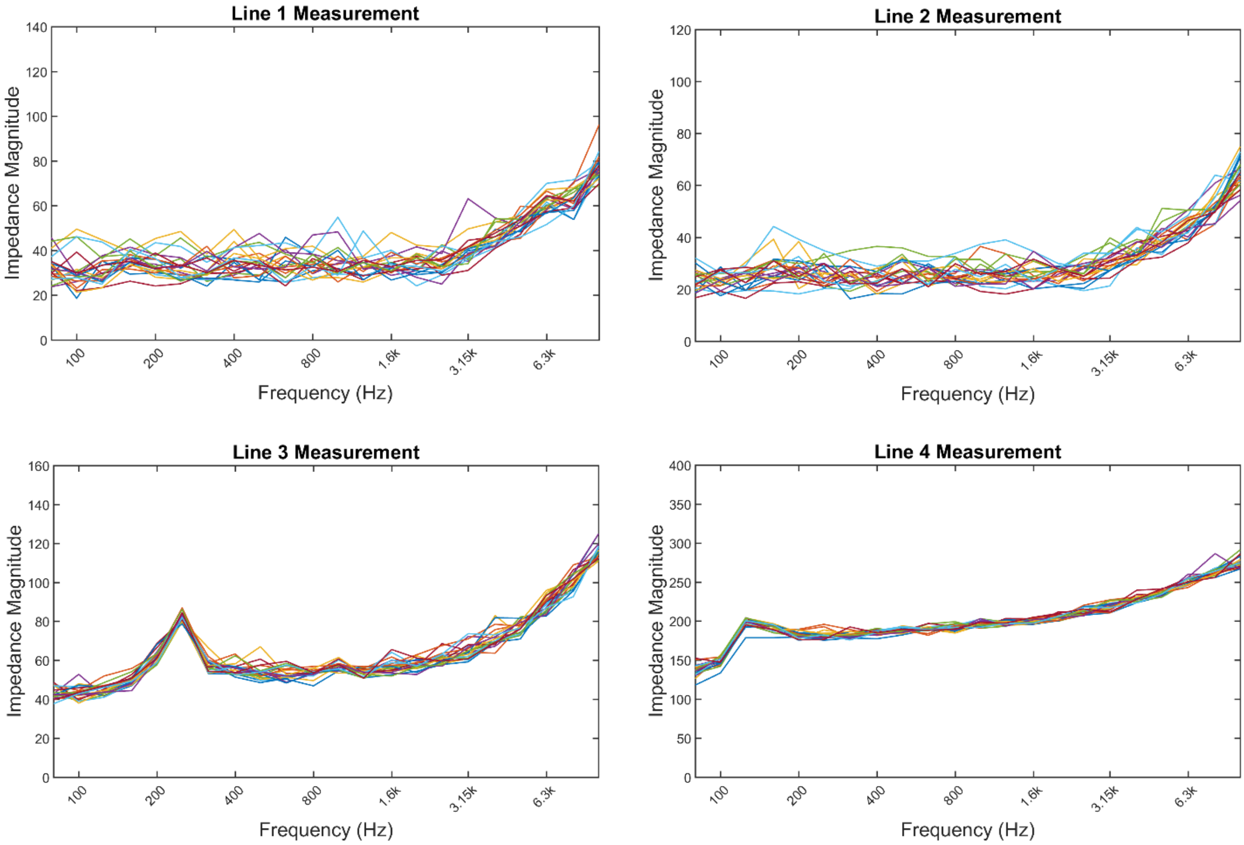

Figure 4: Measurements of the shopping mall lines.

No failure was detected during the measured period, but the measurements show very low variability which indicates that any of the three typical failures can be detected.

As can be seen in Fig. 4, the measurements shows differences as offsets, but the form of the impedance curve remains practically the same. This is caused by the electromagnetic relay array used for the line selector which induces error in the system. The maximum error is seen in the line 3 measurement with ΔZ_n = 17.88. Still, the value is really far from the minimum error found in the reference line measurement, with ΔZ_n = 147.77, so the typical failures should be detected.

4. Conclusions

In this paper, a tool for testing loudspeaker lines is presented. The results of the reference line measurement show its ability to detect the most common failures in distributed audio speaker lines. This tool, nowadays in operation, could be a useful and efficient instrument to detect issues as soon as possible.

During the monitoring time, the system did not present any failure, and no big change in Z_n could be detected. However, the failure monitoring system shows promising future upgrades. Further work may include an improvement in the relay based line selector, in order to obtain more accurate measurement. A change in one speaker may produce small changes in the impedance, which could be detected if the accuracy is increased. Another enhancement, may be replace the resistor used in the measurement by a switchable array of different values. Indeed, if the difference between the impedance measured and the resistor value is large, the distribution of voltage can cause very small values to be measured and the noise in the system can deteriorate the quality of the signal. A useful upgrade may be an alert system via e-mail to aware the system administrator that a line presents a problem, given the ability of the RPI to be configured as a web server.

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