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Development of a mobile electrocardiograph with a wireless warning embedded system

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Abstract

Actually more than 11% of total adult deaths in Mexico City are due to sharp heart attack, which also represents the third cause of deceases in the whole world. The realization of electrocardiograms is a fundamental component in diagnosis and prevention of cardiac diseases, which made the electrocardiograph a medical tool as fundamental as a thermometer. However, actual price of commercial devices do not allow its acquisition and use: even in medical institutions an ECG is conditioned to a previous diagnosis. In this paper is presented a low cost wireless electrocardiograph with a telemedical application embedded, that allows the transmission of a warning signal to specialized personnel about remote patients anomalies in their cardiovascular performance.

Keywords: mobile, electrocardiograph, telemedics

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1. Introduction

According with data published by the Mexican National Institute of Statistics, Geography and Informatics (INEGI), in 2007 in Mexico 8,4% of total deaths were related to heart attack [1]; the next year, just in Mexico City 11,2% of deaths within adult population were due to myocardial infarct (which represented the second cause of death) [2]. Adoption of procedures of heart attacks risk prevention and detection could reduce in a significant way these percentages.

An electrocardiograph is a device that detects and amplifies the heart electrical activity sensed through electrodes attached to the skin surface in arms, legs and intercostals spaces. It is used to measure the rate and regularity of heartbeats, the size and functioning of heart chambers and cardial muscle [3], what, in turn, allows the diagnosis of cardiovascular diseases, metabolic alterations and predisposition to sudden cardiac death.

To generate an electrocardiogram (ECG) the device measures the electrical potential between corporal points where the electrodes are located forming a lead [4]. The range of frequencies of the signal for healthy patients does not have any component above the 60Hz, but the device covers a frequency range from 0.05 to 100 Hz, according to the standard IEC 60601-2-51 [5].

The developed electrocardiograph presented in this paper detects automatically anomalies in different ECG areas through a validation of sensed signals against stored data, and generates audio-visual warnings when measured cardiovascular rates are off the range. The automation in diagnosis avoids uncertainties due to subjective human interpretations of the ECG (derived from fatigue, lack of experience or visual capacity of the responsible for the diagnosis), while the alert adds a telemedical application to the solution: warning can be transmitted to remote locations using an infrared channel embedded in the device.

2. Methodology

To develop the device an experts group (formed with sanity personnel) was consulted about desirable characteristics in the device and about the minimal needs to cover with the graphic interface to show in screen. According with the results in polling and taking in account the need to obtain electrical heart signals with acceptable low noise levels, three modules were considered in the developed device.

In the first module, an instrumentation amplifier avoids electrical heart signal attenuation and fixes the signal for its subsequent processing. In the second module the output analog signal from first module is processed and digitalized, and a warning system activated when frequency heart rate rises is also controlled. Finally, the third module, in which the screen output was designed and implemented, displays the ECG obtained from cardiovascular signal.

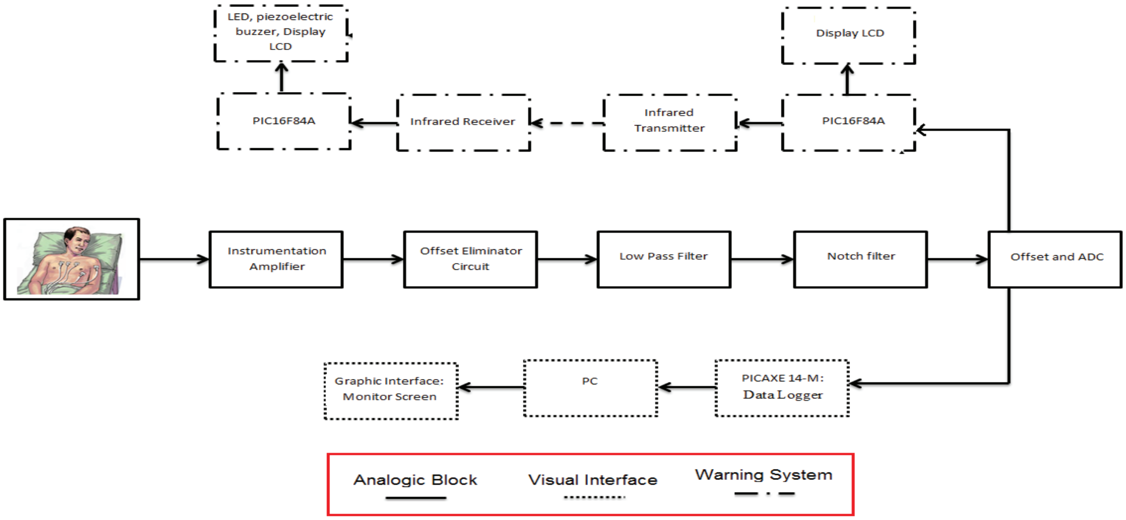


Figure 1. General diagram of proposed solution

General device diagram is showed in figure 1. As is shown in figure, in module one an instrumentation amplifier (compounded by a coupling amplifier and by a differential amplifier) amplifies original cardiac signal using a high impedance electronic circuit (preventing the attenuation of input electrical signal) with high rejection to common mode (avoiding noise).

Instrumentation amplifier diagram is showed in figure 2.

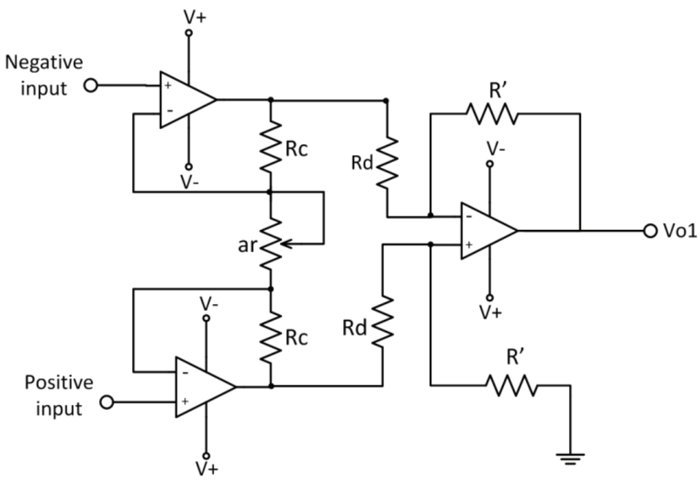


Figure 2. Instrumentation amplifier diagram.

Gain from amplifiers is expressed according to the relations (1) and (2) below:

Coupling amplifier: $$G_C = 1 + 2k, \text{ where } k = \frac{Rc}{ar} \quad (1)$$

Differential amplifier: $$G_D = m = \frac{R'}{Rd} \quad (2)$$

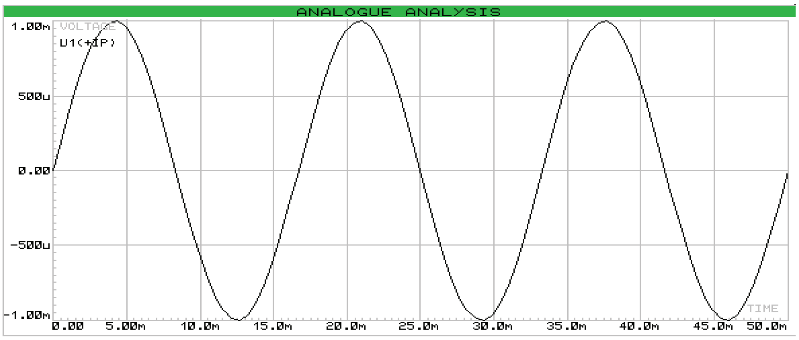
Instrumentation amplifier generates a gain that can be expressed as a product of the gain from coupling amplifier by the gain from differential amplifier, as expressed in (3):

$$Gt = G_C * G_D = (1 + 2k) * \left(\frac{R'}{Rd}\right) \quad (3)$$

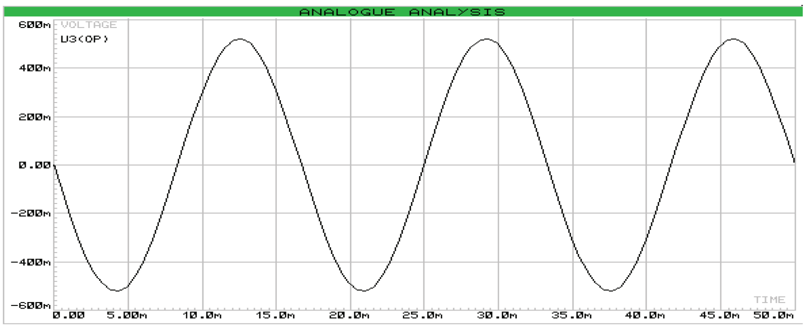
Developed circuit was tested with a test signal of 1 mV, verifying that input signals are amplified with maximal proposed gain (figures 3.a and 3.b).

Final components in first module are two low pass filters, and a notch filter.

First element is an offset filter that eliminates any possible polarization in electrodes using a first order low pass filter for frequencies below the 0.1 Hz, injecting filtered signal to the differential amplifier's non inverting terminal, eliminating any possible current direct signal (figure 4).



a. Input voltage



b. output voltage

Figures 3.a and 3.b. Input and output amplifier signals

The value for resistor in the eliminator circuit on figure 4 is calculated using relation (4):

$$R = \frac{1}{2\pi f C} \tag{4}$$

where: f represents the cutoff frequency, C is the capacitor value and R is the resistor value.

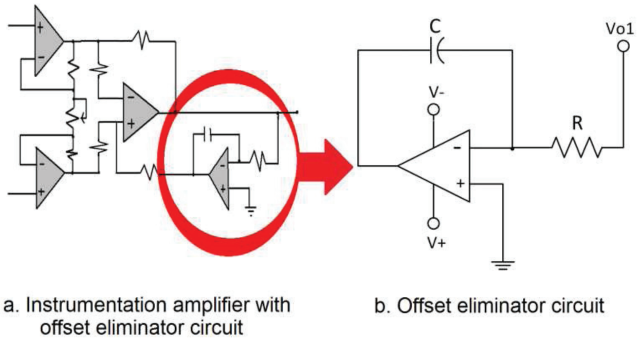


Figure 4. Offset eliminator circuit

Second low pass filter assures that input circuit signals are limited to a frequency range from 0.1 to 250 Hz [6], where electrocardiograph has its more relevant components. As higher the filter grade –higher its selectivity, this low pass filter was realized as a second grade one, with a cut frequency of 250 Hz (figure 5).

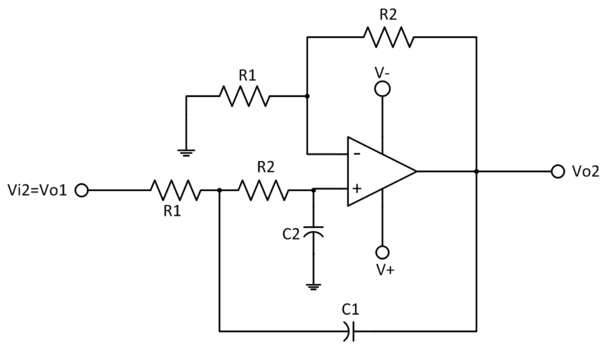
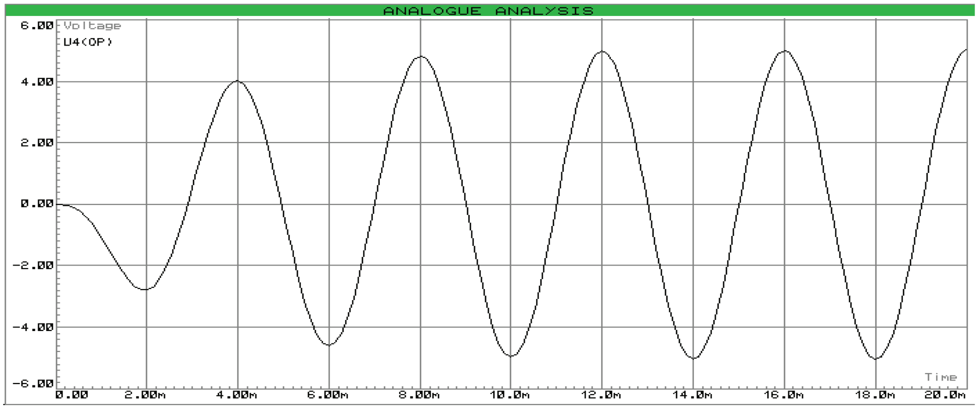
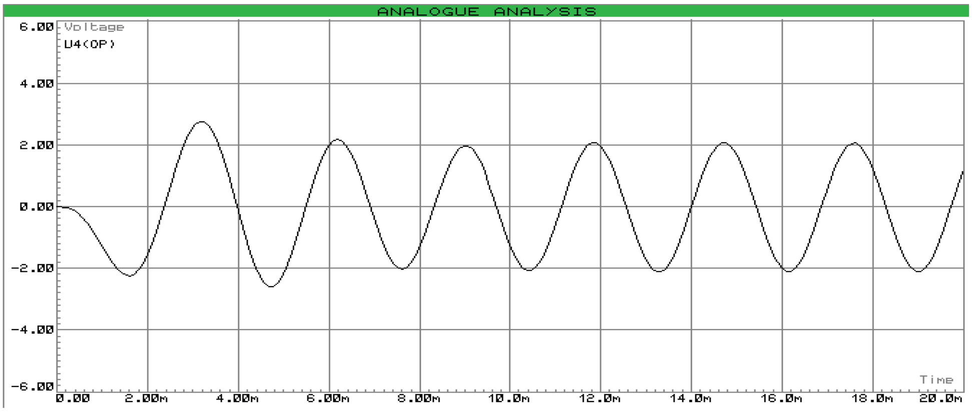


Figure 5.Low pass filter

The filter was tested with two frequencies – 250 Hz and 350 Hz (figures 6.a and 6.b). According with figures, starting from cut frequency (250 Hz) and higher, output signal decreases in amplitude.



6.a.



6.b.

Figures 6.a and 6.b. Output signal for 250 Hz (6.a) and for 350 Hz (6.b)

For applications working with input biosignals that require of preamplification (as the cardiovascular signals, for example), the existence of undesirable noise at the input terminal is very likely, and the implementation of notch filters is needed to eliminate it. As is shown in figure 7, input voltage cross a pass band filter, arriving at the inverter adder twice phase shifted, as long as working signal (output signal from low pass filter) arrives to the adder once phase shifted, which eliminates undesired signals (figure 7).

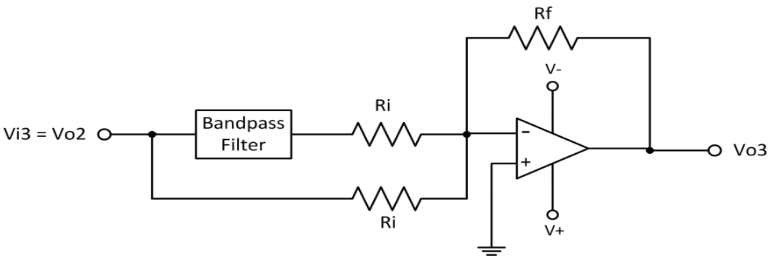


Figure 7.Notch filter diagram

Notch filter was tested for a set of frequencies (40 Hz, 60 Hz and 150 Hz). As it is shown in figure 8, output filter signals form a clear ECG signal.

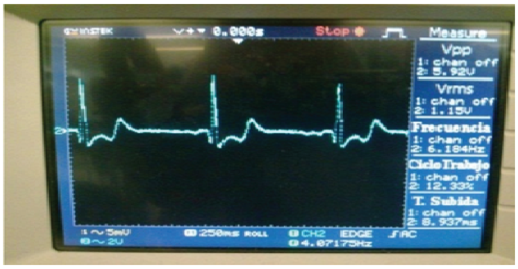


Figure 8. First module output signal

Second module requires from the beginning of a ADC converter to digitalize the output signal from the first module, and of an offset component to assure positive values in signal polarity. The converter used was based in a HEF40106B circuit, an ADC converter with 6 Schmitt triggers [7]. The offset adds a positive direct current voltage to the input working signal using an operational amplifier in non inverting adder mode [7] (figure 9).

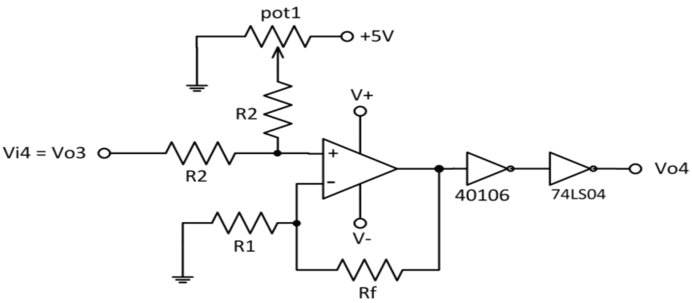


Figure 9.Offset applied to the analog signal

Central component in the module is a PIC18F84Athat realizes the account of heartbeats from the digitalized signal in 6 seconds periods, defining the range of normal heartbeat rate. If during the account period the PIC registers a rate higher than 6 or less than 10 beats, the patient is stable and no action will be taken. Instead, an account of less than 6 or higher than 10 beats (which will mean less than 60 or more than 100 heartbeats by minute, respectively) will activate the transmission channel and a warning signal will be transmitted to the other side of the channel. Together with this warning alert, an LCD screen will show the heartbeat rate. The circuit diagram can be viewed in figure 10.

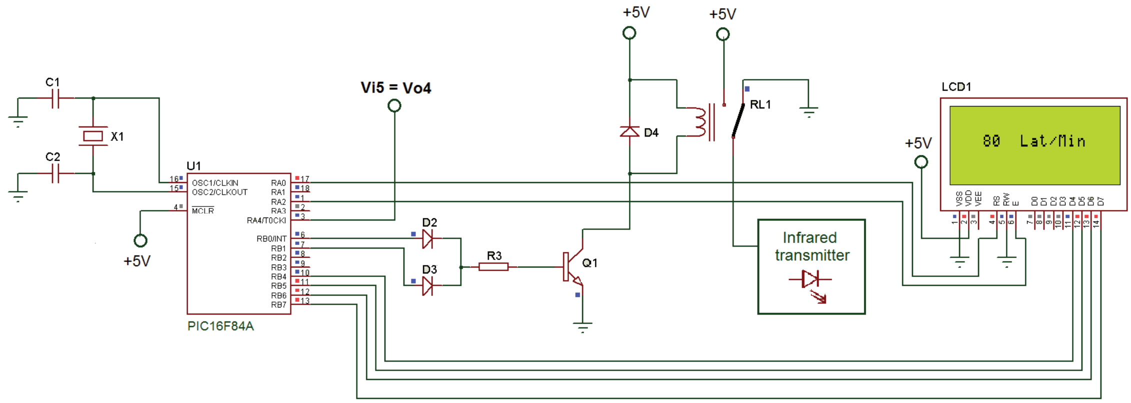


Figure 10.Transmission Control Circuit.

The generated infrared signal is sent using an emitting led with a range of frequencies from 30 to 40 Hz, crossing an LM555 integrated circuit configured in Astable mode (figure 11). This configuration allows the generation of square pulses with a frequency of 30 Hz, voltage levels from 0 to 5V and a working cycle of 50% [8].

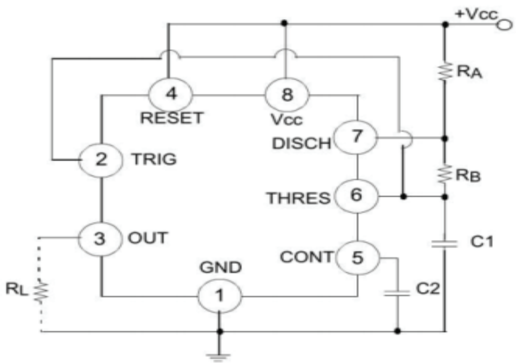


Figure 11.Configuration of the integrated circuit LM555 Astable

In the other side of the channel, while the IR receptor diode does not detect any modulated on its range of frequency signal, circuit output is maintained at high level (5V), but when a signal properly modulated is detected, the output changes to its low level (0 V) in the Vout terminal, processing the signal using another PIC16F84A. This PIC lights three warning pointers: the led, the buzzer and an alert message in LCD display (figure 12).

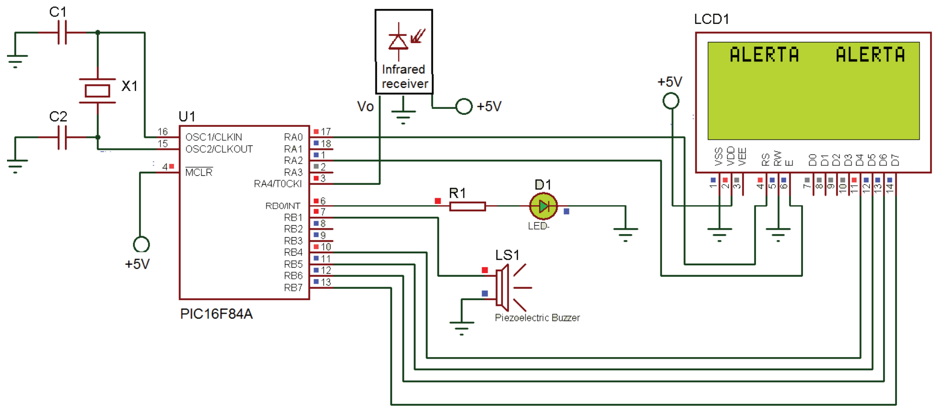


Figure12. Emergency indicator circuit

Third module is basically a visual interface based on Labview 9.0 software, from Network Instruments, showed in figure 13. First module is communicated with this module (located in a remote PC) through a data acquirer (PICAXE-14M microcontroller) [4], controlled by an executable file installable on any PC.

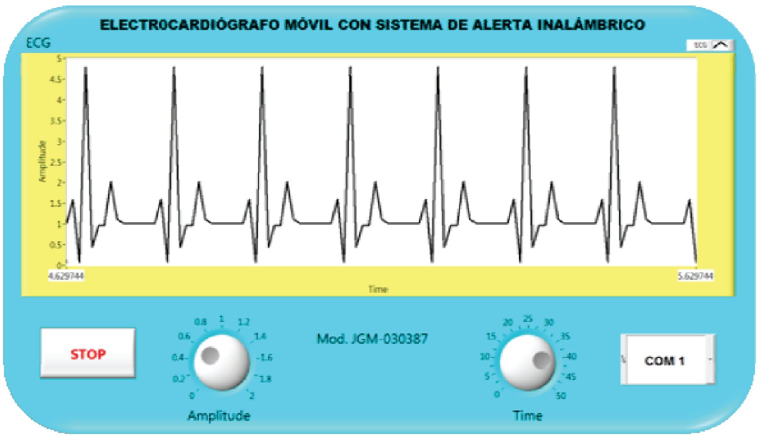


Figure 13. Visual interface (third module)

Figure 13 shows the output signal in an ECG form (showed in Spanish as the interface was programmed). The signal reception is stopped using a stop button located at left side of the screen; the COM input port is selected using another button, located at right side. Although in the prototype the screen shows just the heart electrical activity, a whole measuring virtual platform (which could include patient's temperature and blood pressure, for example) can be added to the interface [9].

3. Conclusions

Developed prototype has been tested in accordance with some guidelines traced in the IEC 60601-1-52 standard, measuring the operators comfort with the visual interface during its performing, the devices exploitation and electrical security parameters and the reliability of implemented algorithms for signal processing. Some test results are summarized in table 1.

Table 1.Electrical test results of the device

Electrical performing test results	
Frequency response	0.05 – 100 Hz
Intrinsically system noise	$< 30\ \mu V$
Avoid factor to common mode	$> 90\ dB$
Permanent output current	$> 300\ \mu A$
Auxiliary patient´s current	$< 50\ \mu A$

Partial test results showed in table one verifies that design and electrical components calibration of the prototype can be evaluated as acceptable in accordance with the standard [5].

It should be noted that during the time the prototype was developed was under testing in a continuous way, to be sure its calibration was adequate through the evaluation of developers’ and some volunteers heart beating, which means that the evaluation group was highly heterogeneous and was not defined any discriminating filter. All the partial tests validate the obtained results, as well as measuring error levels never pass the 28 μV level for input signals below 1 milivolt. Warning alarms were tested through the heart beating measure in cardiac stress tests. For final tests the developers plan to form a new test group, with individuals of any sex and ethnic origin, both healthy and with declared cardiac illness, with ECG tests already done or programmed 5 days after / before the test, which will help in the final device calibration. The final measures should validate the wave P, complex QRS and ventricular extrasistoles lectures, eliminating the possibility of false positives diagnosis.

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