Design of a Digital Sphygmomanometer with Virtual Display

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Abstract—**A digital sphygmomanometer measures blood pressure by means of manipulation of a voltage output signal from a pressure transducer mounted on a pressure cuff. This process is encapsulated by three main circuit components which clean the signal, determine whether systolic or diastolic pressure is being measured, and record and output the desired signal accordingly. We find that our implementation is able to successfully trim noise, produce a usable signal and determine, record and distinguish between the two desired blood pressure values.**

Clinical Relevance— **A sphygmomanometer is used to measure blood pressure as a routine check done by physicians to determine the risk of heart disease, kidney disease, strokes, and other related diseases, and is used as a broad test of general cardiovascular health. Sphygmomanometers are very commonly seen and used in the medical field.**

I. INTRODUCTION

Hypertension is a very common and dangerous condition indicative of various cardiovascular deficiencies, and thus, measuring blood pressure is an extremely common and important procedure performed by various types of doctors.

Blood pressure can vary due to different factors such as exercise, due to the food that has been consumed, or even stress. Blood pressure is commonly shown as two numbers, the systolic blood pressure and the diastolic blood pressure. The systolic blood pressure is the pressure that is measured when the heart is expelling blood out of its chambers into the rest of the body while the diastolic blood pressure is the pressure measured when the heart is refilling its chambers, which is the moment in between the heart beats. Blood pressure measurements can be categorized into four different stages [2]. First is the normal stage in which the systolic pressure is at around 120mmHg or less and the diastolic pressure is at around 80mmHg or less. The second stage is prehypertension where the systolic pressure is between 130mmHg to 139mmHg and the diastolic pressure is between 80mmHg to 89mmHg. This stage is as implied, the stage in which an individual is becoming at risk for developing hypertension. The third stage is Stage 1 hypertension with a systolic pressure of 140mmHg to 159mmHg and a diastolic pressure of 90mmHg to 99mmHg. Stage 1 hypertension is a moderate risk health condition implying that the individual is at risk for developing heart diseases where treatment may be medication, lifestyle changes or a combination of both. The final stage is Stage 2 hypertension where the systolic pressure of an individual is at 160mmHg or above and the diastolic pressure is at 100mmHg or above and this would imply a severe condition of hypertension. The patient at this stage would need immediate attention for treatment which would consist of a similar combination treatment as Stage 1 hypertension but in an even stricter fashion.

The measurement of blood pressure is a common practice that has occurred for over 280 years. This is due to the fact that cardiovascular diseases are the leading cause of deaths worldwide, where symptoms of these cardiovascular diseases include hypertension. Hypertension within individuals is such a common symptom that any person can develop it, even if the person is a child but is mostly a risk factor towards those ages 60 and above [1]. Although the diagnosis of having hypertension may be common, it is difficult to observe without taking blood pressure measurements since it does not have any physical symptoms, hence the existence of devices that measure blood pressure such as the sphygmomanometer.

A sphygmomanometer is one of the most common ways to measure blood pressure. The three main types of sphygmomanometers are mercury, aneroid and digital [1].

The first kind, mercury, uses an actual column of mercury to directly measure the blood pressure in the standard mmHg units. Because of this, the mercury sphygmomanometers are the most accurate of the three.

The second, aneroid, uses a mechanical dial to represent the pressure. While these sphygmomanometers are very reliable, they require calibration and maintenance to yield accurate measurements [6].

The final kind of sphygmomanometer, digital, tends to be the least accurate. Still, it is the most user friendly of the three, and is very common for personal, home measurements of blood pressure.

Each of these devices operates by using an inflatable cuff that is typically wrapped around one of the patient's arms [5]. This cuff is gradually inflated until blood flow is cut off to the rest of the arm. The blood pressure at which blood flow is cut off entirely is the systolic pressure. Then, the pressure is gradually released. For mercury and aneroid sphygmomanometers, the points of systolic and diastolic pressure are usually recognized by applying a stethoscope to a large, shallow blood vessel and listening for sounds of blood flow [5]. When the pressure cuff is wrapped around the upper or lower arm, the brachial and radial arteries are ideal for this purpose. While deflating the cuff the systolic pressure occurs when the sounds of blood flow are first detected. Eventually, the pressure is released enough that blood flows uninhibited through the vessel, and the sounds cease. The pressure at this point is the diastolic pressure. For digital sphygmomanometers, which are often operated by untrained individuals, the device itself determines the points of systolic and diastolic pressure. This can be done by detecting subtle vibrations in the vessel wall [3]. These vibrations are interpreted similarly to the noise heard by the stethoscope. The vibrations beginning marks the systolic pressure, and the vibrations ending indicates smooth flow, marking the diastolic pressure.

II. DEVICE COMPONENTS

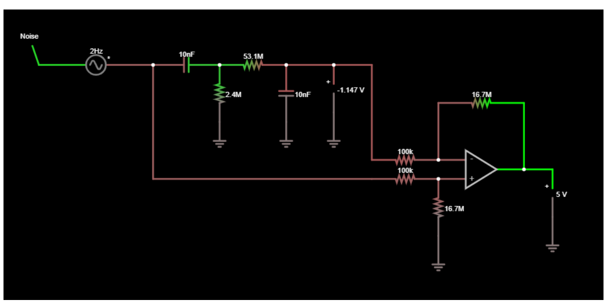

Figure 1. Band-pass filter made up of a first order low-pass filter and high pass filter, and a differential amplifier for extraction of oscillations.

	Resistance (Ohms)	**Capacitance (F)**
High-pass	2.4M	10n
Low-pass	53.1M	10n

Table 1. Parameters for the Resistors and Capacitors in the band-pass filter.

The circuit is composed of three main components, each with a separate specific purpose. The first of these (Figure 1) is directly connected to the voltage output of the pressure transducer, and is fed a signal which includes blood pulses and blood-generated noise. An initial spike in said noise corresponds with the beginning of a pulsing signal, and is identified as the systolic pressure signal; when the noise terminates, the signal represents the diastolic pressure. In essence, this part of the circuit is used to determine the beginning and the end of the Korotkoff sounds, mimicking the function of a stethoscope.

Resistances and capacitances for the band-pass filter were calculated using an online tool. In this case, determining the cutoff frequencies is a matter of examining the biological signals which will be propagated. Although the amplifier scales the voltage signal amplitude, the frequency remains an intact representation of the blood pumping signal's own frequency.

The cardiac pulses which we are concerned with tend to have a frequency in the range of 40 to 120 pulses per minute, translating to lower and upper limits of 0.67 to 2 Hz, respectively. The approximated desired low and high cutoff frequencies implemented were 0.5 Hz and 3 Hz, respectively, and the following formula leads to the resulting parameter values:

$$(1)\ fc = \frac{1}{2\pi RC}$$

Where Fc denotes the cutoff frequency, and R and C represent the resistor's resistance and capacitor's capacitance in both the low- and high-pass filters, respectively.

The amplifier made use of 16.7 megaohm resistors in order to provide a gain boosting the 30 mV maximum output of the pressure transducer to a more usable 5V signal output from the amplifier.

Inputting an oscillating signal combined with noise into the first segment of the circuit, we found that the differential amplifier successfully output the noise exclusively, and that we were able to extract the main oscillating signal. Thus, the band-pass filter was successful and noise isolation, the noise being used later for systolic/diastolic distinction, was achieved.

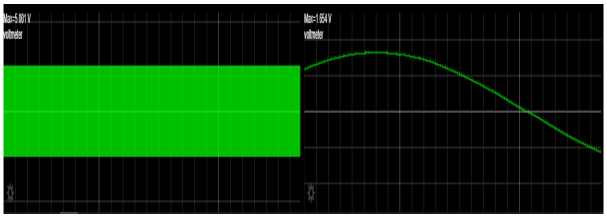

Figure 2. Successfully extracted noise and oscillation signals from the first segment of the circuit.

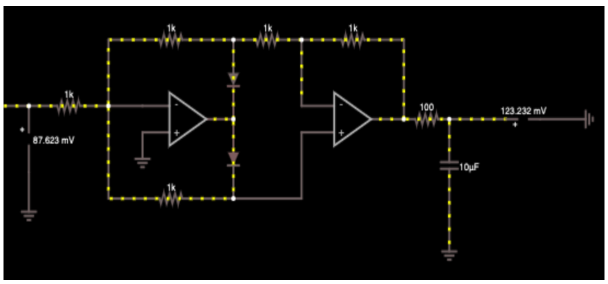

Figure 3. Rectifier represented with two amplifiers, two diodes, and four resistors.

The second part of the circuit smoothens and clarifies the existing signal, and is responsible for the actual securing of both the systolic and diastolic signals. It is composed of a rectifier circuit, and a low-pass filter for smoothing out the rectified signal; the former implements diodes in order to convert AC voltage to DC voltage for more efficient and simplified processing; it does this by means of taking the “absolute value” of the voltage readings and mapping them to an approximate line when given an oscillating signal.

No parameters were calculated for the rectifier; all resistances were kept constant and equal in order to avoid unintentional gain, although they could be used for amplification if so desired. The low-pass filter was artificially tuned in order to demonstrate the rectification and smoothing capabilities of the circuit component; the result of a sinusoidal input converted to an approximately constant output is shown here (Figure 4).

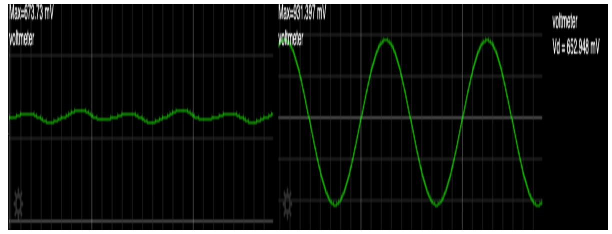

Figure 4. Successfully extracted rectified and smoothed signal on the left and input oscillation signals from the first segment of the circuit shown in Figure 3.

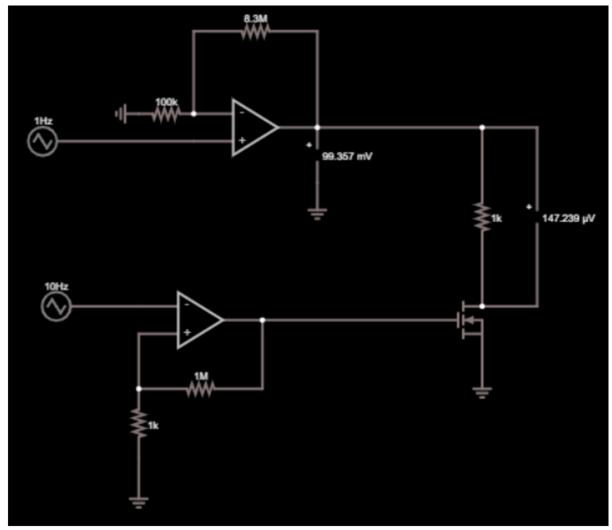

Figure 5. Comparator which outputs an all-or-nothing signal to activate the MOSFET.

The final main component of the circuit is a specialized comparator. At a predetermined threshold amplitude of the oscillation, the comparator saturates and opens a MOSFET gate. The opening of the MOSFET allows the final output voltage of the circuit to be the filtered pressure signal.

Figure 6. The time window of recording the filtered pressure input is successfully determined by an all-or-nothing output signal from the comparator, activating the MOSFET.

This final stage of the circuit by substituting the filtered pressure signal with a low frequency triangle wave, to mimic the gradual drop of pressure in the cuff. Another, higher frequency triangle wave was passed to the comparator, to approximate the roughly arc-shaped signal that would be coming from the rectifier stage of the circuit. When the amplitude of the comparator's input (i.e. the oscillation amplitude) is high enough, it saturates. This opens the MOSFET gate, which switches the output signal from zero, to being the filtered pressure signal. This was successfully tested in figure 6, where the output is controlled to either be zero, or to match the grey line, at the dictation of the comparator. Thus, the recording of the pressure is controlled by the amplitude of the oscillations, with the recorded segment beginning and ending with the systolic and diastolic pressures. This makes obtaining those values a trivial task for the sphygmomanometer device. Testing this device with an actual blood pressure signal, the resistors accompanying the comparator would need to be tuned so that the comparator is only triggered at the desired moment.

V. LIMITATIONS

Several simplifications were made to our system and therefore our circuit. Blood pressure waves were approximated as a sum sinusoidal waves and noise generated. The noise was reported to be due exclusively to the blood as well in order to mimic the function of Korotkoff noise, although other signals might lead to noise and confound the circuit as a result.

For the sake of simplicity, the biological parameter limits used were rounded; a maximum required value of 180 mmHg for systolic blood pressure was brought up to 200 mmHg, and cutoff frequencies were rounded (as mentioned) to 0.5 and 3 Hz.

VI. CONCLUSION

We find that all three separate components of our circuit function in a manner that isolates and preserves the form of the main (decaying) sinusoidal signal representing the pressure, and is able to distinguish between systolic and diastolic pressure. Analysis was performed, as detailed above, by providing appropriate forms of approximated expected signal and noise inputs and watching for expected outputs. Future project development can be concerned with interfacing with particular pressure transducers and implementing on the digital display by means of an Analog-Digital Converter, and ultimately, a digital sphygmomanometer can be constructed of real parts following this design.

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