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An active drop counting device using condenser microphone for superheated emulsion detector

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An active device for superheated emulsion detector is described. A capacitive diaphragm sensor or condenser microphone is used to convert the acoustic pulse of drop nucleation to electrical signal. An active peak detector is included in the circuit to avoid multiple triggering of the counter. The counts are finally recorded by a microprocessor based data acquisition system. Genuine triggers, missed by the sensor, were studied using a simulated clock pulse. The neutron energy spectrum of ^{252}Cf fission neutron source was measured using the device with R114 as the sensitive liquid and compared with the calculated fission neutron energy spectrum of ^{252}Cf. Frequency analysis of the detected signals was also carried out. © *2008 American Institute of Physics.*
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I. INTRODUCTION

Superheated emulsion detector is known to detect neutrons, gamma rays, and other charged particles.[1–4] The detector can also be made insensitive to gamma rays and other lower ionizing radiation by selecting the operating conditions. This property of the detector makes it advantageous in mapping the neutron energy and dose in a complex radiation field such as an accelerator site where there is a strong background of gamma rays.[3,5–7] Another important application of this detector is in the search for cold dark matter, and the potentiality of such detector for weakly interacting massive particles (WIMP) search has been discussed by different groups.[8–10] The nucleation in superheated drops starts with the formation of critical sized vapor bubbles when the energy deposition in the drops exceeds the critical energy.[11] The process of measurement of drop nucleation includes both the passive and active devices. The passive devices are available since the invention of the detector in 1979.[1] It has the advantage of long term unattended measurements without a power source, while the coalescing of bubbles cause limitations at high counting rates. The active device for superheated emulsion was introduced by Apfel and Roy[12] by measuring the acoustic pulse of drop nucleation using a piezoelectric transducer (PZT). There is no such limit in bubble counting except the limitations due to the dead time of the instrument. Later, the electronic superheated emulsion neutron detector, REMbrandt™ and REM-SPEC™ were developed using two PZTs for signal and noise detection.[13] The active devices were developed independently by different workers engaged in the development of superheated emulsion detector in different fields[14–20] using PZT or acoustic emission (AE) sensors. One of the recent developments of the acoustic signal detection is by using PZT coupled to low noise preamplifier[21] and Panasonic microphone cartridge[22] by superheated instruments for massive particle collaboration for cold dark matter search.

In the present work, the active device is developed using a capacitive diaphragm sensor, which is less expensive compared to PZT or AE sensors, a peak detector, a differential comparator, and a microcontroller for data acquisition. The circuit was tested with superheated drops of R114 by irradiating with a ^{252}Cf source. The neutron energy spectrum of ^{252}Cf has been evaluated from the measurement and compared with the calculated one. The frequencies of the true nucleation signal as well as possible noise pick up from the laboratory environment were analyzed. The manuscript has been organized to present a brief discussion on the electronic circuit, measurements, results, and discussions.

II. CIRCUIT DETAILS

A. Acoustic signal detection

The circuit diagram of the active device developed is shown in Fig. 1. The condenser microphone, which is commercially available, has been used in this work to detect the acoustic pulse produced due to drop nucleation. The sensor contains two parallel plates in which one is made of a very light material and acts as the diaphragm. The diaphragm vibrates when struck by sound waves and changes the distance between the two plates and as a result, its capacitance. This gives a corresponding electric signal and the amplitude of the electrical signal depends on the intensity of acoustic signal falling on it. The signal, coupled through a capacitance to the next stage of the circuit, contains many undulations representing the frequency(s) of the acoustic wave, which is modulated by the duration of the acoustic pulse. The amplitude of the output signal from the sensor is within 500 mV, which is fed to the amplifier stage (O1). The signal contains many undulations, which generate multiple triggers. An ac-

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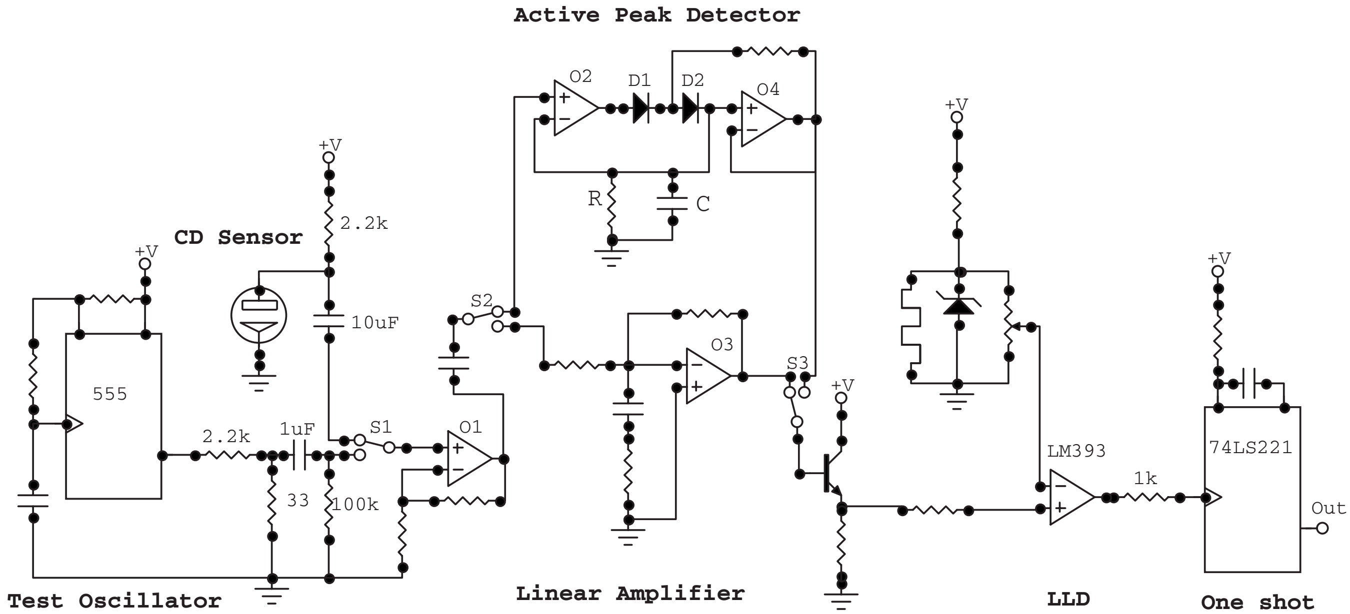

FIG. 1. The circuit diagram of the active device developed.

tive peak detector (O2, O4) is used to avoid these multiple triggers. Field-effect transistor op-amps with very low input bias currents are used. The voltage across the capacitor (C) is held at the rising input waveform of the envelope till it peaks. In the falling part of the envelope, O2 goes to negative saturation, but the feedback from the O4 stage tries to hold the output of O2 at the capacitor voltage. The capacitor discharges itself through the resistance (R) at a rate determined by the time constant of the circuit. The peak detector converts the signal to one having only one peak corresponding to the maximum amplitude of the undulations within the pulse.

The following stage is a differential comparator where a reference voltage corresponding to noise level [low-level discriminator (LLD)] is used. When the true signal is above the LLD threshold, an output signal is generated. The output signal triggers a monostable multivibrator, which gives the appropriate transistor-transistor logic (TTL) output. The pulse width is variable in the range of 4.7 to 243 ms, determined by external resistance and capacitor.

The TTL output pulses are counted by an 89C51 microcontroller based data acquisition system. The built-in timer is used in the gated counting mode to record the counts. A gating time of 1 min is set for the counter. At the end of the gating period, the counter is disarmed, the accumulated count is recorded, and the counter is reset and armed again to count for the next gate duration. The counts are time stamped, recorded in a file, and displayed as count versus time. The counter is set for continuous counting for the duration of the experiment. A four-digit light-emitting diode counter has also been developed for the gross count measurement. The active device circuit board, data acquisition card, and the digital counter developed are shown in Fig. 2.

For diagnostic purposes, an astable multivibrator is included in the circuit to generate TTL signal that can be used to test the performance of the amplifier-discriminator-multivibrator circuit. The test result of the performance of the circuit (next to sensor part) with the signal from the astable multivibrator is shown in Fig. 3. It shows that the circuit needs about 30 min for stabilization and after about 30 min, the fluctuation in the count rate is of the order of 0.5%.

B. ^{252}Cf neutron energy spectrum measurement

The neutron energy spectrum of ^{252}Cf was measured using the active device described above. The sensitive liquid used in the experiment was the superheated drops of R114 ($C_2Cl_2F_4$, bp 3.77 °C) and measurement was done by varying the temperature of the emulsion in the range of 35 to 75 °C. Temperature of the emulsion was varied at a slow rate (about 1 °C per 10 min) by heating the detector vial (15 ml borosil glass vial) with a heating tape. To measure the temperature of the emulsion accurately, a thermocouple thermometer probe was inserted in the gel above the sample at the center of the glass vial. Variation in temperature within the emulsion was about ±0.5 °C.

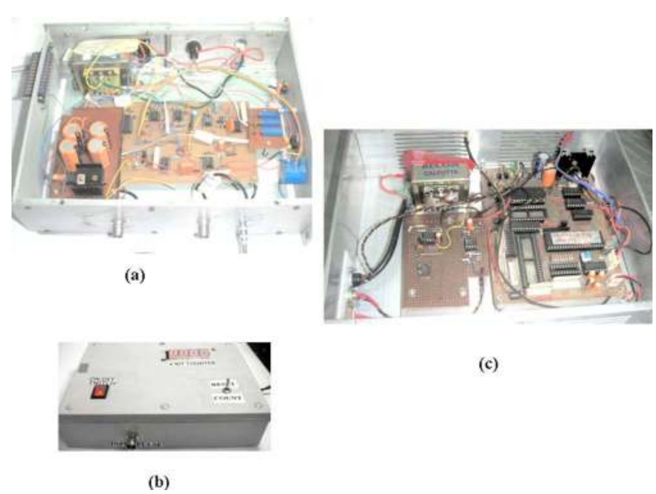

FIG. 2. (Color online) The picture of (a) the active device circuit board, (b) counter, and (c) data acquisition circuit board.

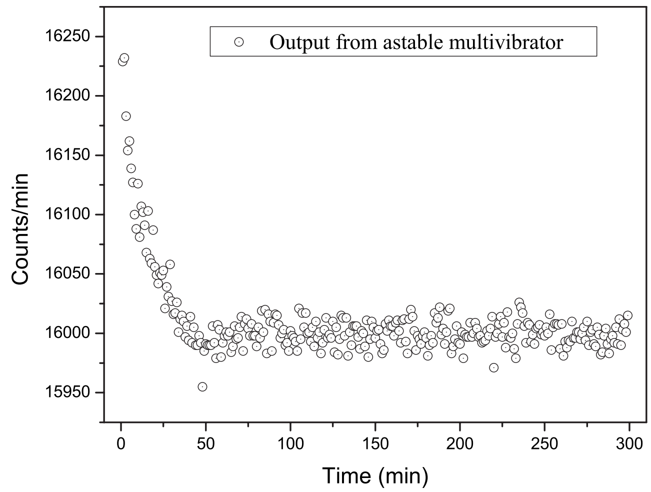

FIG. 3. The test results of the performance of the circuit (next to sensor part) with the signal from the astable multivibrator.

The superheated drops in aquasonic gel medium have been prepared at the Department of Physics, Bose Institute, India and the experiment was done at SINP. The measured data essentially indicates the integrated counts at each temperature. The temperature is converted to the neutron energy using the temperature-threshold neutron energy relationship as explained earlier.[5–7,23]

$$\frac{W}{kr_c}(T)=\frac{dE}{dx}(E_n),$$

where W is the critical energy for nucleation obtained from reversible thermodynamics,[24] r_c is the critical bubble radius, dE/dx is the linear energy transfer (LET) of the significant recoil nuclei for nucleation at a given neutron energy (E_n), and k is the nucleation parameter. The final spectrum is obtained by differentiating the integrated counts. The value of the nucleation parameter k is obtained to be equal to 0.0264.

The variation in observed normalized number of drops nucleated per minute with temperature of the detector is shown in Fig. 4. It clearly indicates the existence of two distinct steps. The first step at the lower temperature is responsible for the nucleation due to neutrons and the second one near 65 °C is due to gamma rays from ^{252}Cf. It has already been reported earlier using ^{241}Am gamma source that the maximum rate of nucleation occurred at a temperature of about 70 °C for R114.[25]

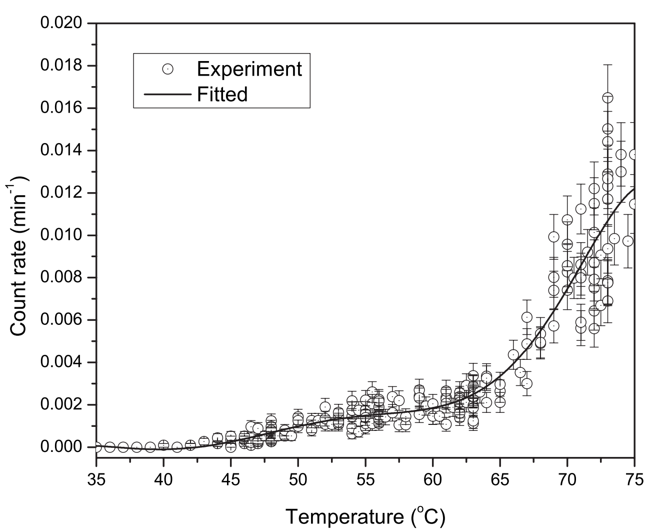

FIG. 4. The variation in observed normalized number of drops nucleated per minute with temperature of the detector.

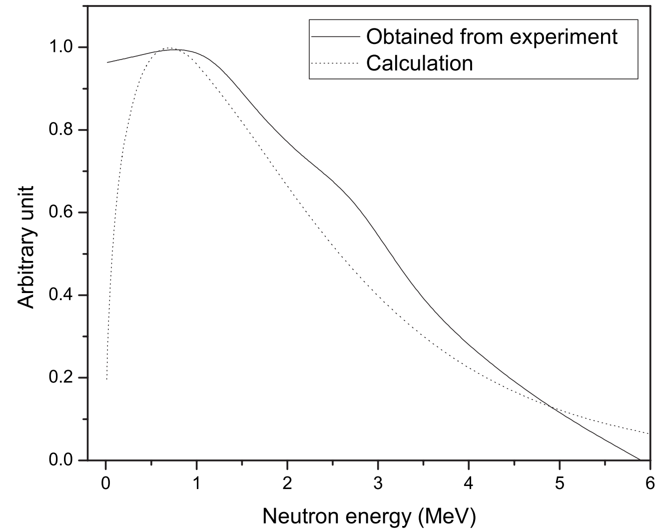

FIG. 5. Neutron energy spectrum of ^{252}Cf obtained from experiment and calculation.

The first step in the experimental observation in Fig. 4 was analyzed for the neutron energy spectrum determination and is shown in Fig. 5. The fission neutron spectrum is calculated, using the formula[26] given below

$$N=108.7\sqrt{0.93E}e^{-0.93E/1.29},$$

which is also shown in Fig. 5. There is a fair agreement between the experimental and the calculated spectrum above about 0.5 MeV. The reason for the observed high sensitivity at the higher temperature is due to the copious emission of gamma rays from ^{252}Cf source and for that the lower energy side of the experimental spectrum could not be improved. As

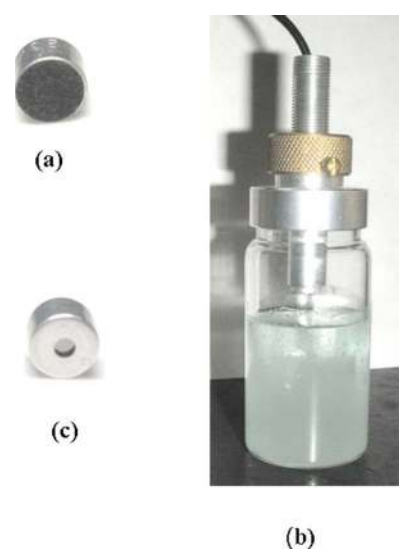

FIG. 6. (Color online) The picture of (a) type-I sensor, (b) microphone holder on sample vial, and (c) type-II sensor,

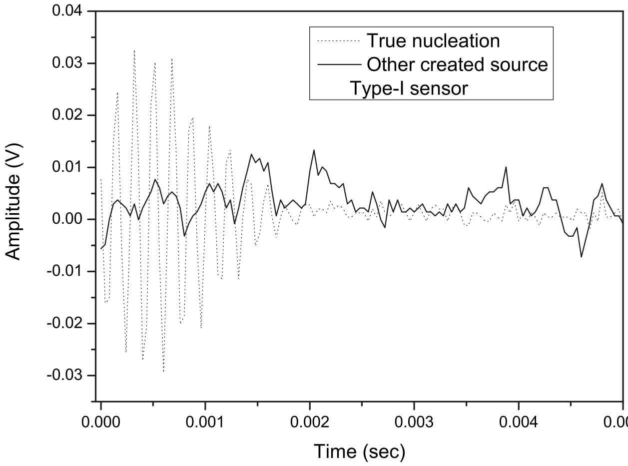

FIG. 7. Waveform from the type-I sensor due to drop nucleation and for possible sound pick up from other source in the laboratory environment.

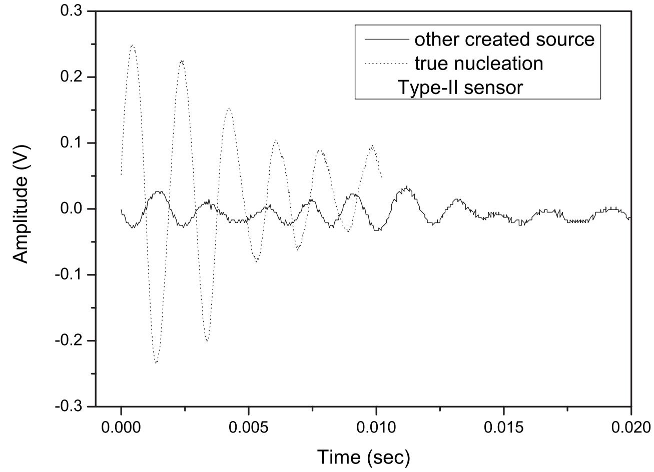

FIG. 9. Waveform from the type-II sensor due to drop nucleation and for possible sound pick up from other source in the laboratory environment.

mentioned above, the detector becomes sensitive to gamma rays at higher operating temperature that corresponds to the lower neutron energy.

III. FREQUENCY ANALYSIS

The condenser microphone used in the present work, is shown in Fig. 6(a). The response of sensor (No. 34B3Y) was observed by putting it inside the vial in air, above the sample. The sensor mounting system made of aluminum (Al) and brass, to the vial is shown in Fig. 6(b). This mounting system provides a stable holding system to reduce the noise pick up, and the vertical position of the microphone inside the vial can be adjusted by the sliding system. It is known that the ultrasonic transmission gel is a good medium for transmission of the acoustic signal without significant attenuation. However, the sensor is difficult to put inside the gel due to the wetting of the front surface of the microphone that affects the sensor response. Therefore, the front surface was covered with mylar foil by putting the sensor inside Al cases (10 mm diameter) of different lengths. This system varies the trapped air gap in front of the sensor by 3, 5, 7, and 10 mm. It is observed that the sensitivity to the sound of drop nucleation increases when there is trapped air in front of the sensor. It is also observed that sensitivity decreases with large increase in air volume. Among the five measurements with and without the air volume, the sensor with 3 mm trapped air shows the best sensitivity and the trace of corresponding signal is shown in Fig. 7. The trace of the signal was recorded in a cathode-ray oscilloscope and digitized using FLUKEVIEW COMBISCOPE software. The sound pick up from all other possible sources in the laboratory environment (e.g., door closure, touching the sensor mounting surface, etc.) are recorded. One of such measurements is also shown in Fig. 7. This type of sound pick up may arise when there are human activities if any, near the sensor system during data acquisition. The fast Fourier transform (FFT) of the sensor signal output gives the frequency associated with the signal, which is shown in Fig. 8 (FFT of Fig. 7). The FFT was done using ORIGIN 7.5 software.

Another model of the condenser microphone, say type II, was also commercially available, which is shown in Fig. 6(c). This sensor has also been tested for sensitivity and frequency analysis in addition to the earlier sensor, say type I, as described above. Type-II (No.37S) sensor has a built-in metal cover in front, and therefore it can be dipped inside the gel. No loss in count was observed while it was dipped in-

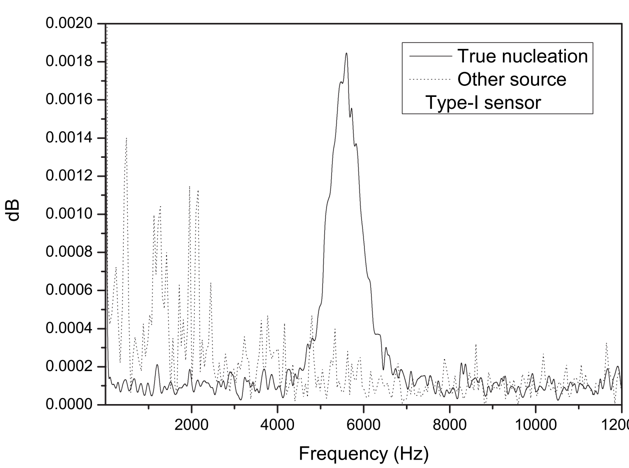

FIG. 8. The FFT of the signal output for type-I sensor of Fig. 7.

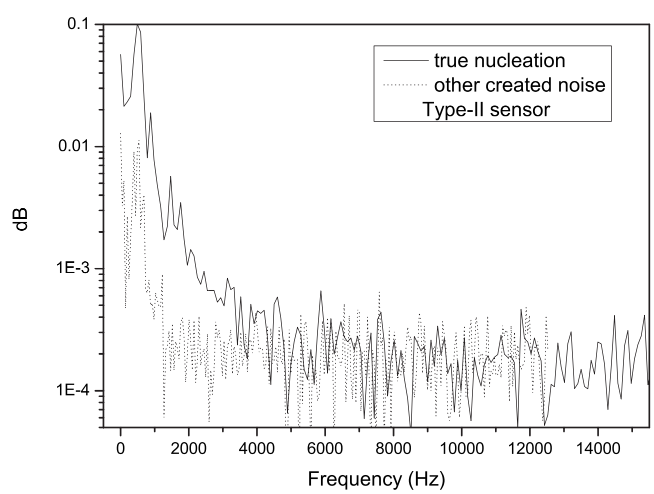

FIG. 10. The FFT of the signal output for type-II sensor of Fig. 9.

TABLE I. Frequency analysis of type-I and type-II sensors in different cases for true nucleation.

	Frequencies (Hz)		
Sensor	In air (Hz)	With different volume of trapped air in front of the sensor (Hz)	Inside gel (Hz)
Type I		5313–6820 for 3 mm	
Type I		1340–1488 for 5 mm	
Type I		739–3818 for 7 mm	
Type I	1100	3796–3922 for 10 mm	No measurement
Type II	587.08	636.01 for 3 mm extra air gap	489.23–684.93

side the gel. The sensor sensitivity does not change if an extra air volume is added in front of it, as was done in type-I sensor. The trace of the signals from the type-II sensor is shown in Fig. 9 and the FFT of the signals are shown in Fig. 10. The frequency of the signal is 587 Hz when the type-II sensor is in air within the vial. However in this case, counting loss by the microphone was observed while the sound of nucleation was audible.

It is observed from Figs. 7 and 9 that the amplitude of true nucleation signal for type-II sensor is larger than that for type-I sensor and therefore, the signal to noise ratio is larger for type-II sensor. The frequencies of both the sensors in different conditions are tabulated in Table I. It is also observed from Figs. 8 and 10 that the frequencies of true nucleation signal and that due to other noise pick up are different for type-I sensor. However these two frequencies are almost identical for the case of type-II sensor. Therefore for the type-I sensor, a band pass filter may be used in the range of 5–7 kHz that can eliminate the noise, which are mainly of lower frequencies.

IV. COUNTING LOSS TESTING WITH SIMULATED PULSE

To account for the count loss, if any, the sensors were tested by a generated clock pulse of width 10 ms ON time and 482 ms OFF time. This simulation circuit consists of an astable multivibrator, inverter, and emitter follower. The output was fed to a speaker. Type-I sensor with 3 mm trapped air in front was mounted with the glass vial (38 mm $\varphi \times 73$ mm) containing gel. The vial was coupled to the speaker by ultrasonic gel. In this case, the sensor was in air, just above the gel, inside the vial. No loss in pulses was observed. The amplitude of the pulses was in the range of 20–40 mV.

TABLE II. Measurement of count loss, if any, by the sensors using simulated pulse.

Sensor type	Number of pulses detected in 1 min	Amplitude of sensor signal output (mV)
Type I	124	20–40
Type II	124	100–250

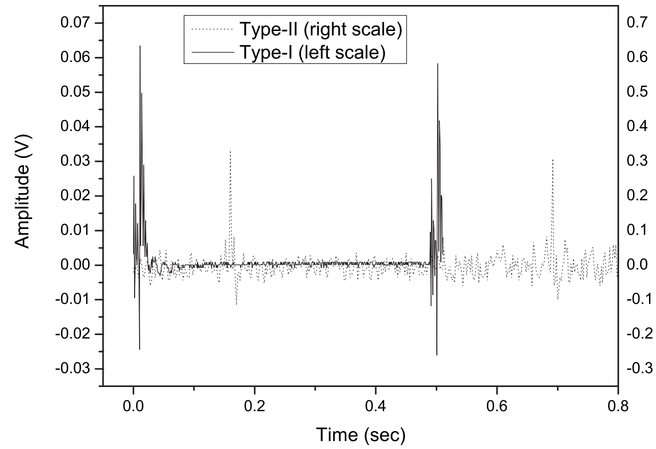

FIG. 11. The output from both the sensors with fixed frequency (~21 Hz) clock pulse.

Similar measurement was done with type-II sensor by dipping it inside the gel. No loss in count was observed in this case also. The amplitude of the pulses recorded by this sensor was about 100–250 mV. The results are given in Table II. The traces of the signal output from the sensors are shown in Fig. 11.

V. CONCLUSION

In this work, the detection of nucleation in superheated emulsion is successfully developed by measuring the acoustic pulse with condenser microphone, which is relatively inexpensive and easily available, followed by signal rectification, trigger generation, and finally a microprocessor based data acquisition system. The performance of the condenser microphone for different possible cases were analyzed to extract the best arrangement. Both the models of the sensor are useful in detecting the acoustic pulse of drop nucleation, type-I sensor with the trapped air in front, and type-II sensor by dipping inside the gel. The neutron energy spectrum of ^{252}Cf fission source was measured using the device and compared with the calculated one, indicating a good agreement. The results also indicate satisfactory performance of the active device and data acquisition system.

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