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Designing a Customized Analog Display in Lab – Observed Issues and Their Solutions

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Abstract — In a measurement system, the measured entity is exhibited to the user using a display or indicating system. This display unit can either be analog or digital. In several applications, an analog indication is preferred over digital. This paper deals with a customized analog display unit that forms the part of a newly developed sensor which performs a specialized application. As this customized display system caters to some special features of this new sensor, it can be used for similar applications also in future. The main objective of this paper is to illustrate the problems that were encountered while designing this customized display unit and the corrective modifications taken to eliminate those. These modifications make the new analog display more reliable.

Index Terms— Analog indication, Comparator, Display, D flip-flop, Indicating unit, Moisture sensor, Voltage clamp

1 INTRODUCTION

In any measuring instrument, its display unit becomes the final link between itself and the user. The instrument becomes reliable and user friendly, when its display unit presents the processed data in an understandable manner to the user [1]. Data can be presented to the user either in analog form or in digital form. Several varieties of both these displays are available. When compared to digital indicators, the analog systems are very simple and generally consist of moving pointers or LED displays. In certain applications, the user will be more interested to know the severity of the indicated parameter, rather than the actual value of it, as for e.g. the intensity of sound in a music system [2]. This can be effectively communicated using LED displays. In this paper, the design of the analog indication for such kind of an application is presented with emphasis on the issues encountered during the design and their solutions.

The background to the development of this analog indicating system is a real-time sensor that was newly developed to detect the presence of dissolved moisture in the insulating oil of power transformers. Power transformers are vital components in an electrical power network. As increased levels of dissolved moisture in the oil reduces the life of the transformer, continuous moisture evaluation is necessary to keep the power system healthy. Hence a sensor was designed for this application. The sensor provides routine information about the dissolved moisture content in the oil as an output voltage which is proportional to the 'ppm' or parts per million of the moisture content in the oil at the time of measurement. The sensor is designed to perform the measurement once every day at a particular set time. The sensing completes in about 2 minutes and the ppm value should be indicated in the display. The mode of operation of this sensor is such that it first resets its output before a measurement. After this, the sensing commences and the output increases from zero to finally settle at a value proportional to the dissolved ppm after 2 minutes. Following this sensing period, the output once again reduces back to zero to remain so until next measurement. Hence a compatible display which indicates the sensed ppm until the next measurement had to be developed. The choice finally went to an analog indicating system; the primary reason being the cost factor. The whole sensor was designed such that it costs less than 10% of the price of existing similar sensors in market which ridiculed the use of any micro-controllers (MCs)/processors, ADCs (Analog to Digital Converters) and other interfacing units in it. Since a digital display needed these components to work, an analog indication scheme was the only solution for this case. Secondly, from the user's perspective too an analog indication was found adequate, as a LED based analog display can effectively express the severity of the increasing trend in the dissolved moisture using multi-coloured LEDs that indicate different ranges of ppm values. Once the sensor output exceeds the set threshold voltage level for a particular ppm range, the next severity level will glow and by noting down the number of days required for a new severity level to glow, the rate of increase of the dissolved moisture can be estimated.

There are different kinds of analog display topologies designed according to the application – some use ICs to set the thresholds as for e.g., the temperature sensing system in [3] uses analog indicating ICs such as LM3914, LM3915 etc. [4], while others are more simpler without any IC, like the water level indication in [5], where the water level itself takes the role of the thresholds to light up the LEDs. However, none of the above topologies can be used for this sensor because, as mentioned earlier, the required display should work such that it continuously indicates the ppm range until the next measurement starts, in spite of the fall-back of the sensor output to zero after the sensing period. As per their working style, neither of the above topologies will be able to sustain the indicated output after the sensing period until the next measurement, if used. For this new sensor, an IC-based topology is only suitable. However, in it, the ppms are indicated in non-uniform ranges. Hence a non-uniform, custom-built resistive potential divider arrangement was required for setting the threshold for

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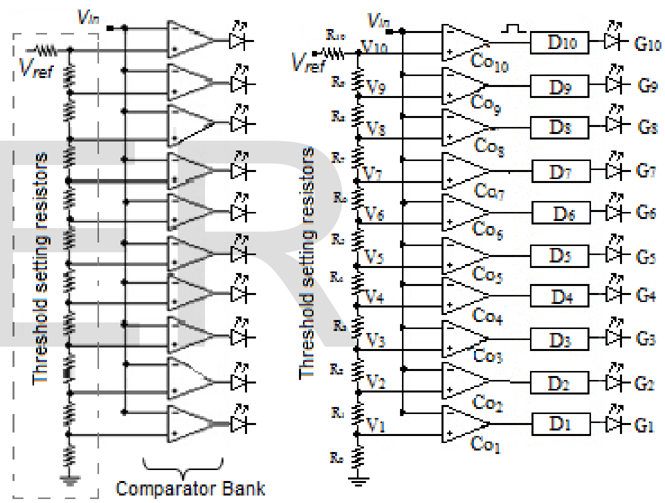
each severity level in this application. As the above mentioned ICs have a uniform potential divider arrangement and that too internally, they once again become unsuitable for this application. Hence an altogether new analog indicating system had to be designed for this new sensor. One of the key expected features for this new indicating system was the presence of externally accessible threshold setting resistors that can be adjusted to set the ppm ranges as per the users' specifications.

The proposed display unit has been designed with components that are normally available in all electronic labs so as to reduce the overall cost of the sensor. However, some issues were seen during its design and had to be resolved. This paper highlights those issues and explains their solutions so that they can be used as a reference for designing similar analog indicating systems in the future. The proceeding section explains the basic structure of the proposed display unit.

2 Structure of the New Display

Fig. 1(a) shows the structure of a common IC-based display system. The comparators compare the incoming voltage V_{in} with their respective threshold levels set by the resistive potential divider assembly which is connected to a reference voltage V_{ref}. The threshold level at each comparator is determined by the values of resistors in that assembly. When the V_{in} crosses the threshold level of a comparator, its output will go high, switching its LED ON. When the incoming voltage drops below the threshold, the LED will go OFF as the comparator's output goes either zero or negative. Normally the potential divider arrangement as well as the comparators is internal to an IC as in LM3914 [4], however for specific requirements, the potential divider assembly is constructed externally as well.

As mentioned earlier, the new sensor has a non-uniform indication range and therefore the non-uniform resistive threshold setting assembly was made separately using actual resistors of various values. The assembly was set in such a way that each level is proportional to a particular range of ppm of moisture. Fig. 1(b) shows the basic structure of the proposed display unit. Since it has been developed with the most commonly available ICs in a lab, five TL082 operational amplifier ICs [6] were used to constitute the 10-level comparator array. Unlike other indicating circuits mentioned earlier, since the previous measurement output has to be retained till the next one here, latch ICs 7474 [7] which are basically D flip – flops were used at each comparator's output for this purpose. The outputs of the comparators (Co_1 to Co_{10}) served as clock pulses to these positive-edge triggered latches (D_1 to D_{10}) and each latch would set its output to high when its associated comparator output went high. Fig. 2(a) shows the generated sensor output V_{in}, three set threshold levels (among the total 10) namely V_8, V_9, & V_{10} and the responses of the respective comparator & latch. When V_{in} exceeds V_8, the comparator Co_8 will go high (refer Fig. 1b). The same applies to V_9 as well, but since V_{in} is not crossing V_{10}, the output of the corresponding comparator Co_{10} will remain low itself until the next measurement. Hence latches D_8 and D_9 will be set, while D_{10} will be in reset mode. As a result, the respective LEDs will glow; indicating that the ppm value is within the range written next to the highest priority LED (which is G_9 in this case) on the PCB (Printed Circuit Board) of the sensor. The comparators Co_8 and Co_9 will go low once the sensor output drops after sensing. However, since D_8 and D_9 respond only to positive edged clock pulses; their outputs will remain high until the start of the next measurement (the time difference being 24 hours) during which they will be reset temporarily using a signal given to their reset pins by the sensor. Now, all the previously indicated values will disappear and fresh values will be exhibited after the end of the new measurement. Thus the proposed new display works. However, since this display has been built with multiple ICs in an amateur manner, it had some issues which prevented it from working properly. Hence it was not as reliable as the single IC-based display topologies mentioned earlier in [4]. As no other single IC consisting of 10 manual threshold setters, 10 comparators and 10 latches were available in the market for this application; these issues had to be solved before applying it into the sensor. Hence the proceeding session explains those observed issues and the corresponding corrective measures adopted for their rectification.



(a) (b)

Fig. 1 (a) Structure of the normal display unit showing 10 levels of indication. Resistors internal to the IC are shown in dotted box. (b) basic design of the proposed display unit

3 Encountered Issues and Their Solutions

The primary problem that was observed soon after the circuit in Fig. 1b was laid on board was heating of the comparator and latch ICs. During analysis, if was found that the heating was due to two reasons. One was the voltage difference between the output of comparator ICs and the clock input of the latches. While the former was about 10 V, the latter was about 4 V. This was corrected by introducing appropriate potential dividers between the two as shown in Fig. 3, where R_x and R_y are the potential dividers. The second reason for heating was the current sinking into the output pins of the comparators from the clock pins of the latch ICs, when the comparators' output went low during the fall of V_{in}. This was prevented by connecting normal power diodes IN4007 (D_{VC}) [8]

as shown in Fig. 3.

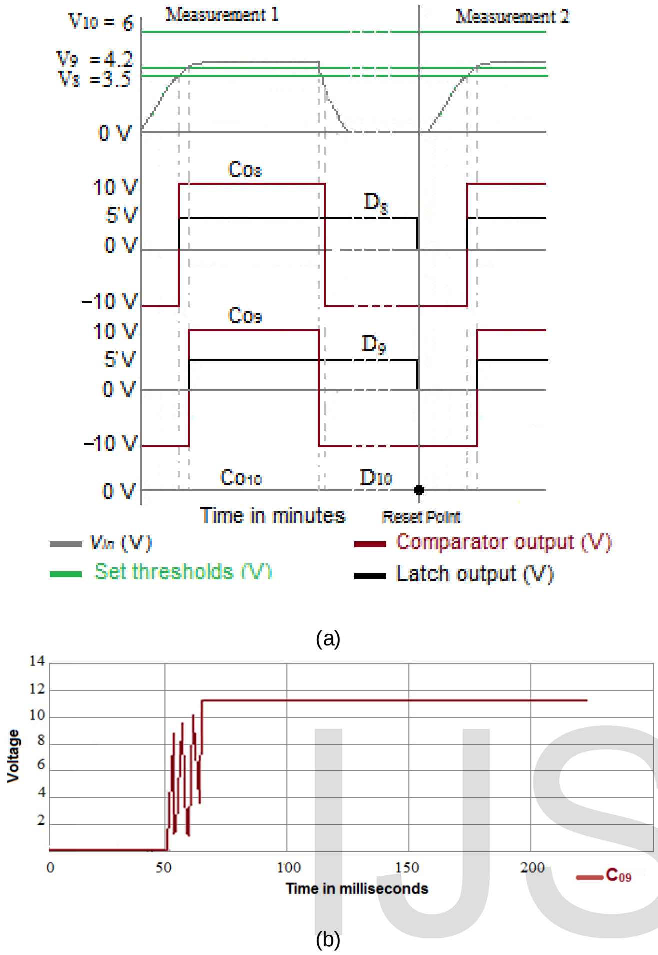


Fig.2. (a) Voltage waveform of the sensor output and the corresponding outputs from comparators and flip - flop. For better understanding, only three threshold levels are shown here. Also the measurement time between 2 subsequent measurements are shown in minutes instead of 24 hours. (b) Zoomed version of the waveform of Co_9 showing fluctuation at its positive edge.

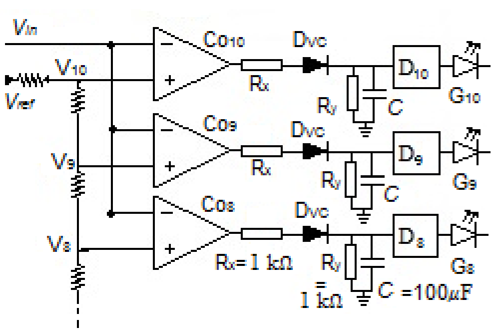


Fig.3. Modified display unit with R_x, R_y and filter capacitors for each level. For better understanding, only three threshold levels are shown here

Another problem that was encountered during the design was the fluctuations seen in the positive edge of the output of the comparator that was indicating the final ppm range. For a particular ppm, when the voltage from the sensor was about to stabilize near the threshold voltage of this comparator as shown in Fig. 2a, the ambient noise was forcing the sensor output to fluctuate above and below the threshold value for some time, resulting in some high frequency fluctuations at its output as TL082 ICs have a very fast response. Since the comparator output is given as the clock to the corresponding D flip – flop latch, these fluctuations will appear as level-shifting clock pulses to it. Hence they will go high and low in consecutive positive edges of these spurious pulses. Depending upon the number of these fluctuations, the latch will set its final output which can be either ON or OFF. As a result, the corresponding indicating LED will be also either ON or OFF and if in case if it's an OFF, the next severity level will not be indicated giving wrong judgment to the user. Hence this was a serious issue.

In order to resolve this problem, the first thing that became handy was the placement of those diodes D_{VC} that were introduced earlier. These diodes acted as positive voltage clamps during those fluctuations. However, since these were normal power diodes and the frequency of those fluctuations were much higher, they were not completely effective. Hence a Low Pass Filter (LPF) had to be designed that would eliminate the high frequency fluctuations. A LPF is basically an R-C element and some resistors had been already introduced between the comparator and the latch for voltage matching. Hence taking advantage of this, only a suitable value of the capacitor C had to be now introduced to materialize the filter. Selecting an upper cut-off frequency of 5 Hz, a 100 μF capacitor was introduced along with R_x and R_y = 1 kΩ and the fluctuations subsided. The corrected comparator output is as shown in Fig. 4. When compared to the sharp rising edges in Fig. 2b, the output now has a higher rise time due to the effect of the LPF. However, this is insignificant as only a single rising edge is now present for triggering the latch. Finally, after all these modifications, all the observed issues were solved and the new display started working as expected. An image of the new customized analog display along with the sensing module is shown in Fig. 5.

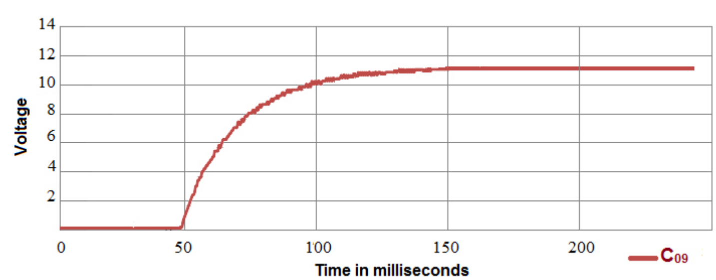


Fig.4. Corrected comparator output

4 Discussion

The proposed display unit uses multiple numbers of latch ICs and comparator ICs in order to make it suitable for the requirements of the newly developed sensor. However this makes the total power consumption by the unit slightly higher. The TL082 IC has two operational amplifiers serving as comparators and the latch IC 7474 has two D flip – flops fabri-

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cated within [6][7]. Each measurement level of the display unit requires a comparator and a latch. Since there are ten levels of measurements, five numbers of each IC have to be used. This makes the total power consumption by all the ICs in the display approximately equal to 300 mW. This is a drawback from the perspective of the powering source, even though the sensor works for just 2 minutes in a day. Hence this power consumption should be reduced to as minimum as possible and the solution to this is to reduce the number of the ICs. Presently, an IC that is available in the market with maximum number of operational amplifiers inside a single chip is TL084 [9] which contain four comparators. Similarly IC 74LS175 [10] contains the maximum number of latches in it, equal to four. To make a ten level measurement setup, two number of each of these ICs can be used along with one 7474 and one TL082. By using such a setup, the power consumption will reduce to 177 mW, which is about half the previous value. When ICs with more number of comparators and latches in a single chip are available in the market, the power consumption will be further reduced. Other than this only drawback presently, this customized analog display devised using simple components in the lab is perfectly compatible with its sensor and renders its function effectively, without any errors, after all the modifications.

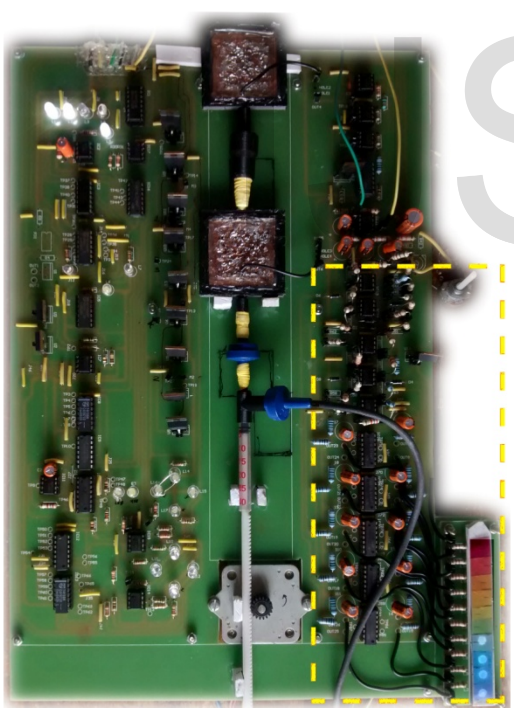

Fig.5. The new customized analog display (shown in dotted box) along with the sensing module.

5 Conclusion

Analog displays are used for some specialized applications as in the case of the newly developed sensor mentioned in this paper. This sensor had to sustain its output until the next measurement, which takes place after every 24 hours. Since the existing analog displays ICs available in the market are incompatible with this requirement, a new display had to be designed. As cost was also a factor of consideration, this display was designed using components normally available in an electronic lab, such as comparator and latch ICs. After the design, a few issues were found out such as, heating of ICs and unnecessary triggering of latches. The heating of ICs were solved by introducing suitable voltage dividing resistors between the comparator ICs and their corresponding latches. Besides, a diode was added to prevent the reverse flow of current from the latch to the comparator at each stage, which was another cause of heating. The unnecessary triggering of latch IC caused by spurious fluctuations in the comparator's output was removed by transforming the voltage dividing resistors and the diode into an RC filter between the comparator and its latch, by adding a suitable filter capacitor. After these modifications, all the observed issues were found resolved and the new display performed exactly as intended. However its power consumption was found slightly higher, but this can be reduced by reducing the number of ICs. As this paper explains a few issues observed while designing a customized analog display with low-end components for a specialized application and their solutions adopted, the authors, through this paper, hope to help a future designer who wishes to make a similar display, to know in advance about the likely problems that he may encounter, and design accordingly for better results.

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