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An instrument system for digital display of duration of bright sunshine

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ABSTRACT. The article describes an instrument system designed in the Instruments Division, Meteorological Office, Pune to provide a digital display of daily duration of bright sunshine in the units of hours and minutes. Provision has been made in the instrument to store the data so as to provide an indication of the total duration of bright sunshine for the last 24 hours and also for one day (24-hr) previous to that. The instrument can also be used as sensor for interfacing with Automatic Weather Station Systems.

1. Introduction

Duration of bright sunshine in a day is an important meteorological parameter since it becomes an approximate inverse measure of cloudiness. It is also an important parameter in plant physiology, *e.g.*, studies on photosynthesis require information regarding bright sunshine. The duration of bright sunshine is also used in the estimation of evaporation and evapotranspiration (Schulze 1976, Lumb 1964, WMO 1966). The Campbell-Stokes type sunshine recorder has been the universally used instrument for the measurement of the hourly or daily total of the duration of sunshine over a period and this instrument has been in vogue for decades in many countries. With the development of automatic weather stations the need to design a simple sensor system that could work unattended for obtaining this information was felt. The present article describes such an automatic system recently designed at the Instruments Division, Meteorological Office, Pune. A photoelectric sensor monitors the sunshine and the system displays the total duration of bright sunshine in hours and minutes in numerical digital form. The time information in the system is derived from a crystal clock and is thus very accurate even over long periods of unattended operation.

The instrument system described here is simple to use, accurate and is easily constructed. Compact in size and having very low power consumption, it can be used with automatic weather stations also. COS/MOS integrated circuits have been used in the construction since they provide high noise immunity, good fanout characteristics and also consume very low power.

2. Principle of operation

The output of two photocells, which are exposed to identical conditions of illumination are balanced electrically against each other. One of them is then shaded from sunlight. During sunshine the other exposed cell gives more output and the difference voltage developed across the cells connected in oppositon is amplified. The amplified output is applied to the noninverting input point of a voltage level comparator of which the inverting input point is earthed and is thus always at zero potential. The comparator output goes high when the voltage difference between its noninverting and inverting points goes above a certain threshold value. The output of the comparator is gated with the one minute pulses derived from a crystal controlled clock. The logical gated output then drives a 4 digit minute and hour counter to register the duration of bright sunshine. Provision is made to display the counter reading in numerical digital form.

3. Circuit description

A schematic block diagram of the system is shown in Fig. 1.

It consists of the following main parts :

(*a*) The sensor,

(*b*) System electronics for measurement and integration of the duration of bright sunshine and

(*c*) Power supplies.

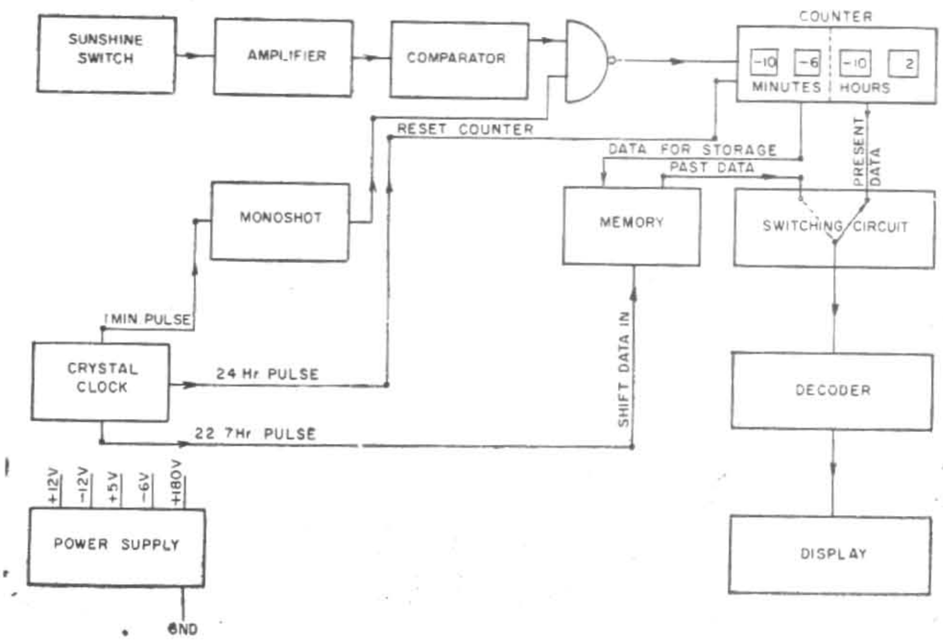

Fig. 1. Block diagram of duration of sunshine integrator

The following paragraphs highlight the salient design details and describe the sensor, system electronics, and power supplies in some detail.

3.1. *The sensor* (*Sunshine switch*)

A photoelectric sunshine switch of the type which was in routine use for many years in United States weather observatories has been selected as the sensor (Fig. 2). In this a cylindrical tube is used, and it is masked so that the light is allowed only to diffuse through about 1" wide translucent rings each located towards the end of the cylindrical tube. A baffle of light tight partition is cemented inside the glass tube to divide it into two equal parts. About one inch lengths of the tube on either side of the baffle are painted black on the inside to render them opaque to the direct and diffused light which may be incident on the tube from out side. Both the baffle and masked areas are then covered with the white paint to scatter as much light as possible to the two photo tubes (photoelectic cells Weston No.856 RR barrier layer type, hermitically sealed) mounted under the translucent portions near the ends of the tube. These photocells are capable of giving an output of 4 microamperes per foot-candle under an illumination of approximately 50 foot-candle as per USWB specification No. 044-1421 (1956).

The photocells are connected in electrical opposition. Being located near the translucent portions of the tube towards either ends of the Potopal glass tube, they give an equal electrical output under the same conditions of illumination. In the sunshine switch the tube carrying the photocells is supported by a simple equatorial mount with the provision for a guard ring which prevents direct sunlight falling on one end of the tube and the amount of light diffused inside the tube and reaching the corresponding photocell is less than that reaching the other photocell in bright sunshine. Provision is also there to move the guard ring up or down in a direction coaxial with the major axis of the tube in order to take care of seasonal variations in the sun's declination. Thus under normal exposure and in the absence of sunlight, both the cells are practically under similar conditions of diffused illumination and give practically equal electrical outputs which are nearly balanced out in the differential mode of operation (Fig. 3). Whenever bright sunshine is present, more diffused light reaches the photocell located near the unshaded end of the tube (*i.e.*, away from guard ring) and the outputs of the two photocells remain no longer balanced. This imbalance thus indicates the presence of bright sunshine and its total duration in a day is found as described in the subsequent paragraphs.

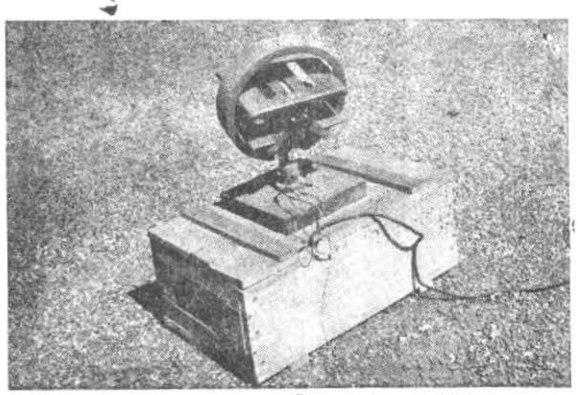

Fig. 2. Photoelectric sunshine switch

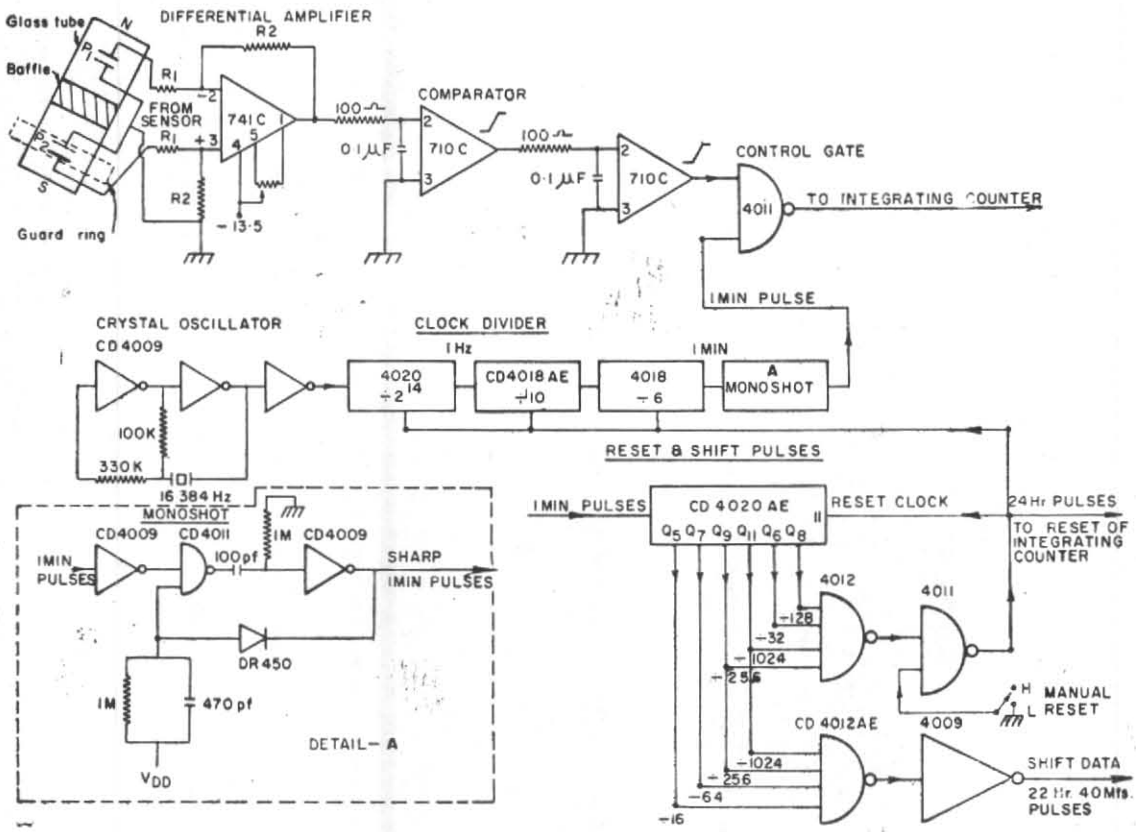

Fig. 3. Amplifier and clock diagram

3.2. *The system electronics*

(*i*) *The amplifier* — The voltage output from the sensor is amplified by using an operational amplifier (μA 741C) in the differential mode as shown in Fig. 3. The amplified output is applied to a voltage level comparator. This comparator (μA 710) gives a positive output (high) when the input voltage level exceeds 5 mV between its inverting and noninverting input points. For fast terminal response, two comparators are cascaded.

(*ii*) *The clock* – Fig. 3 shows the crystal clock used in the system. The clock is designed to give regular output pulses at every 1 min, 22 hr 40 min and 24 hr. A 16.384 kHz glass encapsulated crystal is used together with the inverters (COS/MOS CD 4009) in the basic oscillator circuit oscillating at 16.384 kHz. The one minute pulses are derived by sub-dividing this frequency by using the counters CD 4020 and CD 4018. Likewise the 22 hr 40 min and 24-hr pulses are derived by further frequency subdivisions of one minute pulses. The 22 hr 40 min and 24-hr pulses are used to shift the last 24-hr data in the system memory and to reset the clock counter respectively.

The 24-hr reset pulses and 22 hr 40 min shift pulses are generated by using another fourteen stage binary counter (CD 4020) with gating as shown in Fig. 3. For 24-hr pulses which are used to reset the clock and the counter, the terminals Q_{11}, Q_9, Q_8 and Q_6 and for 22 hr 40 min pulses which shift the data, the terminals Q_5, Q_7, Q_9, and Q_{11}, of CD 4020 are gated using a 4 input NAND gate (CD 4012). For manual reset of the clock and the counter, a push button switch is provided on the system panel. The clock is very accurate.

(*iii*) *Pulse shaping and gating* — The output of the voltage level comparator, and the one minute pulses derived from the crystal clock, are fed to the two input terminals of a two input NAND gate (CD4011). The one minute pulses need to be made very sharp and narrow using a monoshot before they are connected to the input of the NAND gate. The width of the pulse is determined by the circuit components of the monoshot (Fig. 3). A sharp and narrow pulse is necessary to avoid random counts which might occur due to the extraneous electrical noise at the output of the comparator. The one minute pulses at the output of the monoshot are gated in to the counter only when bright sunshine is present, *i.e.*, when the comparator output is high.

(*iv*) *The sunshine duration integrating counter* — The output of the NAND gate drives a four

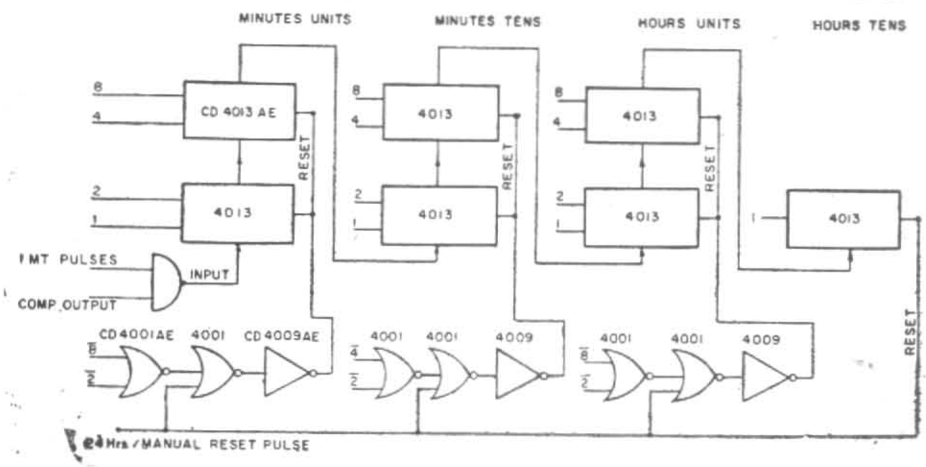

Fig. 4. Time integrating counter

digit BCD counter which counts in the units of hours and minutes. The counter uses dual flip-flop (CD 4013). For getting units and tens of hours and minutes, the flip-flops have to be reset by proper gating. To implement a divide by ten counter, the reset pulse is obtained by gating the output of 8 and 2 states. To realize a divide by 6 counter the outputs of 4 and 2 states of the counter are gated. Thus a divide by 60 counter is implemented giving units and tens of minutes. Similarly units and tens of hours are implemented. All these counters are also reset by the 24-hr pulse derived from the crystal clock. As shown in Fig. 4, integrated circuit CD 4001 and CD 4009/(RCA) are used for implementing the necessary logic. The counters are also reset whenever the clock is reset.

(*v*) *Memory circuit* — The system has got a memory which can store a day's data. This memory provides the duration of sunshine for the preceding day. The past data is shifted to the memory after a suitable predetermined time (22 hr 40 min). COS/MOS IC CD 4018 is used as a shift register for shifting the data in by connecting the inverted counter outputs to its jam inputs. As the outputs from CD 4018 are inverted, $\overline{8}$, $\overline{4}$, $\overline{2}$ and $\overline{1}$ are are used at its inputs to get proper 8, 2, 4, 1 at the output.

The shifting of past data is done before the resetting of counter and this operation is normally executed in the night when there is no sunshine (*i.e.*, after every 22 hr 40 min from the system reset).

(*vi*) *Switching of past-present data* — Integrated circuit COS/MOS 4016 bilateral switch has been used to switch the current or past data from the memory to display. Both the current and past data are present at the inputs of a different set of IC's, CD 4016 (Fig. 5). These data can be swtiched to the decoder driver by making the control points of the respective CD 4016's high or low depending upon the users choice. The control points of CD 4016's are connected to a switch (DPDT), S_1, as shown, by the dotted line and solid line in Fig. 5. The dotted line goes high and the solid line low for switching of past data. The solid line goes high and dotted line low for the switching of current data. By the operation of the S_1 switch, present or past data can thus be selected for display. The swtich S_1 is located on the front panel for easy accessibility.

(*vii*) *Decoder and display* — The BCD output obtained at the outputs of CD 4016 are connected to decoder/drivers (SN 7441) through buffers CD 4010. The buffers CD 4010 makes COS/MOS outputs compatible with TTL 74141. The decoded outputs are fed to the cathodes of Nixie display tubes XN-3. To the anode of XN-3, 180 V is applied though 22K resistors. In place of Nixie-tube display, LED display can also be used. LED display requires only nominal 5 V DC for operation. Incorporating LED display thus makes the use of mains high voltage supply unnecessary. Fig. 6 shows the circuit schematic for the 7 segment LED display.

(*viii*) *Adjustments of sensor* — The sensor is mounted north-south, its axes making an angle with the horizontal equal to the latitude of the station.

The shade ring is shifted up or down periodically as the sun moves north or south with the season so that the top photocell is shaded from the direct sunlight. The following is the standard shade ring setting schedule for any latitude in the northern hemisphere for the shunshine switched used.

Change to upper	—	13	April
Change to middle	—	30	August
Change to lower	—	11	October
Change to middle	—	28	February

(*ix*) *Threshold adjustment* — The threshold is adjusted on a clear day. For getting the bright diffused sky light the middle of the day is preferred

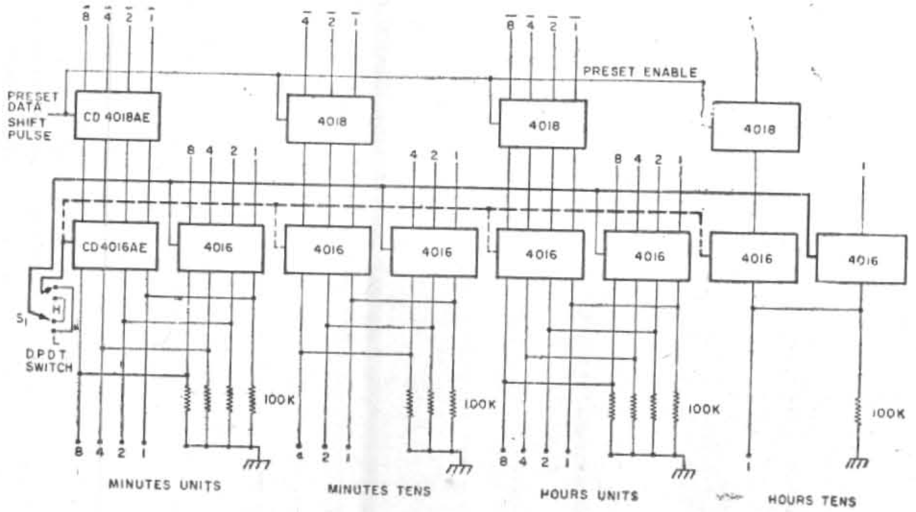

Fig. 5. Memory and switching

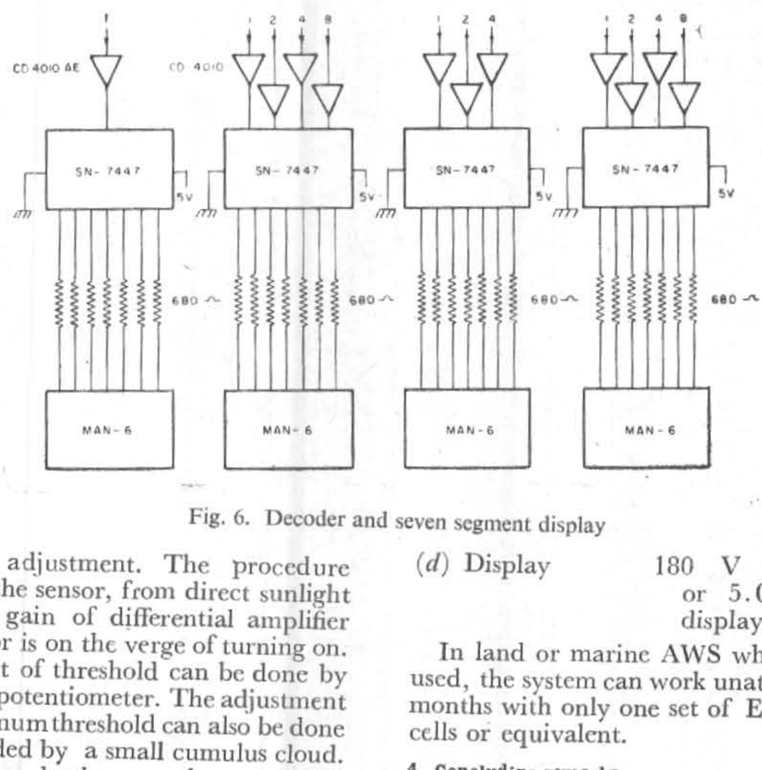

Fig. 6. Decoder and seven segment display

or the threshold adjustment. The procedure consists of shading the sensor, from direct sunlight and adjusting the gain of differential amplifier until the comparator is on the verge of turning on. The fine adjustment of threshold can be done by adjusting the offset potentiometer. The adjustment in gain for the minimum threshold can also be done when the sun is shaded by a small cumulus cloud. The cloud should completely cover the sun and be large enough so that no bright edge is in evidence.

3.3. *Power supply*

3.3.1. The system requires the following power supplies :

(*a*) ± 12.0 V DC (Regulated)	For linear IC's, *i.e.*, OP-AMPS and comparators
(*b*) + 5.0 V DC (Regulated)	For COS/MOS and TTL IC's
(*c*) − 7.0 V DC (Regulated)	For comparator
(*d*) Display	180 V (for Nixie tubes) or 5.0 V DC for LED display.

In land or marine AWS where display is not used, the system can work unattended for about 4 months with only one set of Eveready 6 G dry cells or equivalent.

4. Concluding remarks

Duration of bright sunshine is an important meteorological parameter in so far as it becomes an inverse measure of cloudiness. Its automatic and unattended measurement is required for including the duration of bright sunshine as one of the parameters in the scheme of an automatic weather station. At present four main types of instruments namely, (a) the Campbell Stokes pattern, (b) The Marvin pattern, (c) The Jordan pattern, (d) The Foster photoelectric sunshine switch are in use. Among all these four types the Foster photoelectric type sunshine switch is probably the most

TABLE 1

Date (1977)	Time duration (IST)	Sunshine duration by Campbell Stokes sunshine recorder h m	Sunshine duration by digital display h m	Difference h m
29 Sep	1000-1700	04 30	04 43	00 13
30 Sep	1000-1700	05 00	05 15	00 15
1 Oct	1000-1700	03 42	03 52	00 10
2 Oct	1000-1700	03 30	03 45	00 15
3 Oct	1000-1700	02 15	02 05	—(00 10)
4 Oct	1030-1700	02 30	03 05	00 35
5 Oct	1000-1700	02 54	03 15	00 21
6 Oct	1000-1700	03 30	03 47	00 17
7 Oct	0600-1000	02 35	02 57	00 22
10 Oct	1000-1700	07 00	07 00	00 00
11 Oct	1000-1700	07 00	07 00	00 00
12 Oct	1000-1900	07 20	07 45	00 25
13 Oct	1000-1900	07 40	08 00	00 20
16 Oct	1000-1700	07 00	07 00	00 00
17 Oct	1000-1700	10 50	02 03	00 13
19 Oct	1000-1900	06 30	06 40	00 10
22 Oct	1000-1700	05 40	06 00	00 20
31 Oct	Sunrise to sunset	09 50	10 00	00 10
2 Nov	,,	03 15	03 50	00 35
3 Nov	,,	03 00	03 15	00 15
4 Nov	,,	04 35	04 50	00 15
6. Nov	,,	04 35	04 50	00 15
8 Nov	,,	03 58	04 06	00 08

suitable for application in automatic weather stations.

It has been recognised that the differences of upto 20 per cent in monthly totals can occur while using different type of instruments and recording paper and by the methods used for the measurement of records. Since 1962 the Campbell Stokes recorder has been adopted as the interim reference sunshine recorder (IRSR) and efforts are made to reduce the values of duration of sunshine recorded by other methods to this reference. The reduction factor needs to be determined by careful comparison over a period of several months (WMO 1971).

A precise quantitative lower threshold limit of the intensity of direct solar radiation has not been defined since this is not practical. The IRSR standard corresponds roughly to an average lower limit of 21 mW/cm^2.

The present stystem was field tested at Pune over long periods and the readings compared generally well with the data furnished by the Campbell Stokes sunshine recorder. Table 1 shows a typical set of observations taken in the months of September, October and November on 23 different days and it is seen that the digital sunshine duration integrator indicated values of bright sunshine duration in a day which were on an average upto about 14 minutes in excess of those recorded by C.S. sunshine recorder. The system described in the present article would thus appear to be suitable for application in automatic weather stations. It is simple in construction and fairly accurate in long term unattended performance. The minimum consumption of power and ability to operate unattended with batteries over long periods has dictated the choice of COS/MOS integrated circuits. Making the one minute pulses very sharp and narrow before gating to the integrating counter is a special design feature to ensure that the noise from the sensor, amplifier and comparator does not advance the integrating counter which would otherwise result in an erroneous reading. Shorn of the display circuit which may not be required in AWS application, the sensor, amplifier comparator and integrating counter necessitates the use of under fifteen IC devices (The clock pulse would normally be available from AWS master clock itself). The lag of the instrument is negligible and its overall sensitivity allows reliable measurements at dawn and dusk.

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