Development of Electronic Hygrometer System

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Abstract

Hygrometers are generally applied in the meteorological (weather) stations, industries, laboratories and at homes to determine the moisture content in the air or humidity. They could be of mechanical or electronic design. This paper presents a cheap, affordable and efficient electronic means of measuring and controlling humidity at homes and in industries. The system comprises of: a power supply unit, a humidity sensor/buffer unit, a precision half-wave rectifier/amplifier unit, an ac source generator, a buffered analogue ($V_{cc}/2$) reference ground unit and an output unit (a meter and switching control). It has the ability to measure the relative humidity automatically. Above a preset level of 80%, the switching control output through the action of two Darlington transistors operates a relay which in turn switches on any device connected to it. This device tends to dry up the air surrounding the sensor thereby reducing the relative humidity. And once the value drops below 80%, the device deactivates. The hygrometer can be used to provide a direct display of the relative humidity and control the switching of some appliances such as air conditioners and air dryers, once the value exceeds 80%. The electronic hygrometer thus plays a significant role in humidity measurement and control environments by providing or allowing a high level of accuracy, faster response time and lower levels of hysteresis.

Keywords*: Humidity, relative humidity, power supply, sensor buffer module, half wave rectifier, Schmitt trigger control circuit.*

Introduction

The earliest record of humidity measurement was the use of an instrument called hygrometer in the mid-fifteenth century by the Germans. In 1450, a German cardinal philosopher, and administrator, Nicolas Cryfts (1401-1464) described the first hygrometer with the following: “if someone should hang a good deal of wool, tied together on one end of a large pair of scales, and should balance it with stones at the other end in a place where the air is temperate, it would be found that the weight of the wool would increase when the air became more humid, and decrease when the air tended to dryness”. In 1481, an Italian artist, scientist and inventor Leonardo Da Vinci (1452 – 1519) drew Nicolas Cryft’s hygrometer in his codex atlanticus, using a sponge instead of wool. The purpose of the hygrometer, according to Da Vinci, was to know the qualities and thickness of the air, and when it was going to rain. This was known as the crude hygrometer. (Anon. 1992a; Anon. 2006c).

In 1614, Santorio Santorre, a Brazilian, developed a hygrometer that measured vapour by the contraction and elongation of cord or lyre strings. Later, hygrometers were made of wood, seaweed, pair, hair, nylon, beard and acetate. The best known type of hygrometer is the “dry and wet bulb Psychrometer”, best described as two mercury thermometers, one with a wetted base, one with a dry base. The water from the wet base evaporates and absorbs heat causing the thermometer reading to drop. Using a calculation table, the reading from the dry thermometer and the wet thermometer are used to determine the relative humidity.

(Adeleke *et al.* 2004). One early version of a wet and dry hygrometer was made by John Frederic Daniell, an English scientist, in 1820 (Anon. 1992a, Anon. 2006c; Anon. 2006e; Bellis 2006; Sonntag 1994).

Technological advancements in semiconductor industries led to the discovery of different kinds of electronic humidity sensors; (the brain behind electronic hygrometers) which includes capacitive, resistive and thermal conductivity humidity sensors, respectively. (Godel *et al.* 1992; Sakai *et al.* 2000). They have virtually replaced their mechanical counterparts due to their high level of accuracy, faster response time, lower level of hysteresis and lower cost. Humidity affects the thermal, electrical, optical and transport properties of gases. It also influences a vast range of physical, chemical and biological processes. The prevailing humidity can determine whether substances corrode or can cause dimensional changes in materials (Sonntag 1994).

Design and Implementation

Modular Structure

Fig. 1 shows the generalized block diagram of the system which was composed of the following major modules:

(i) Regulated Power Supply module;
(ii) 555-Based *ac* generator module;
(iii) Buffered $V_{cc}/2$ reference module;
(iv) Sensor/buffer module;
(v) Precision half-wave rectifier/amplifier module;
(vi) Control (Schmitt Trigger) output module.

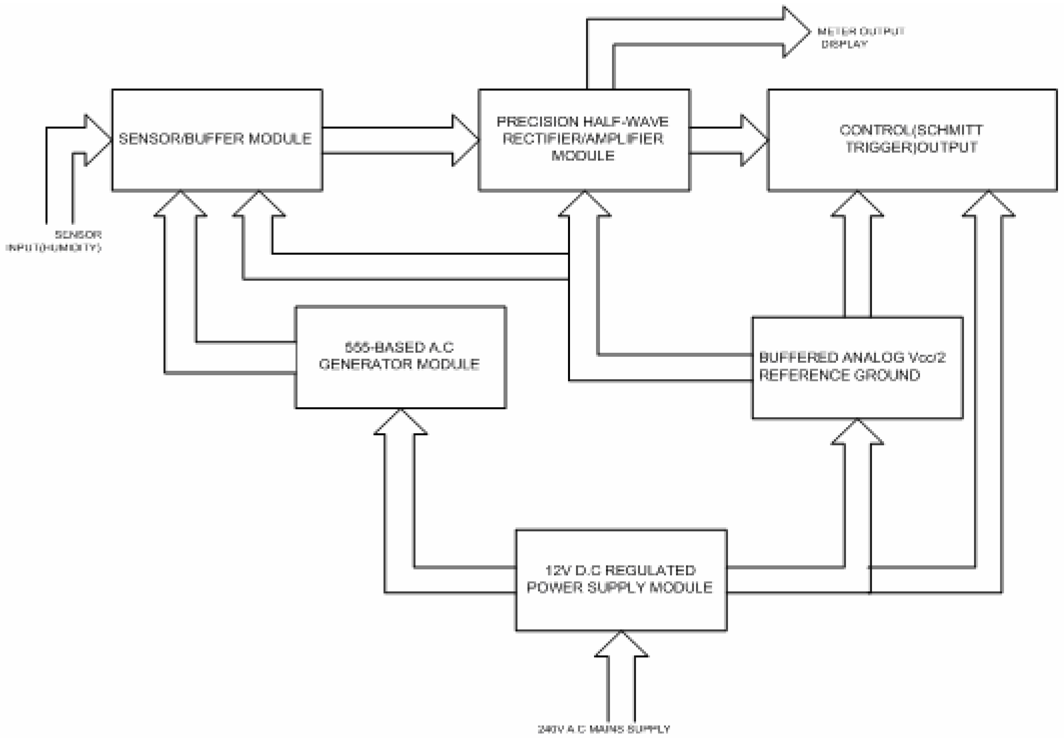

Fig. 1. Generalized block diagram of the circuit.

Power Supply

This unit supplied a regulated 12V *dc* to the entire circuit as shown in both Figs. 1 and 2, respectively. A 12V, 0.5A transformer, packaged 2A bridge rectifier system and 2,200nF capacitor were employed. The 12V *ac* output at the secondary winding of the transformer was rectified to yield a pulsating *dc* output. This was regulated by IC7812, 1A, to provide a very stable +12V *dc* supply for the system. The peak secondary voltage,

$$V_{pk} = 1.4142 \text{ x } 12 = 16.97\text{V}, \qquad (1)$$

can be used to obtain the peak full wave rectified voltage at filter input,

$$V_{ip} = V_{pk} - V_{rms}. \qquad (2)$$

From Eq. 2,

$$V_{ip} = 16.97 - (2 \text{ x } 0.7071) = 15.56\text{V}.$$

Also,

$$V_{dc} = V_{ip} / (1+1/4f\, C\, R_L), \qquad (3)$$

where f = 50Hz, C = 2,200nF, R_L = 2kΩ. From Eq. 3,

$$V_{dc} = 15.57\text{V}.$$

This *dc* voltage was fed into IC7812 regulator to produce a regulated 12V *dc* needed to power the system.

555-based *ac* Voltage Generator

A 555 astable oscillator circuit was used to implement an *ac* controlled source as shown in Fig. 3. It was wired in the standard astable mode with an output frequency calculated from the relation:

$$f_o = 1.44 / (\, R_A + 2\, R_B)\, C, \qquad (4)$$

where $R_A = R_{14}$, $R_B = R_{15}$, and $C = C_8$ generated the square wave output frequency as shown in Fig. 4.

The duty cycle of the output square wave can be obtained from the following relations:

$$T\,(\text{High}) = 0.693\,(R_A + R_B)\, C, \qquad (5)$$

$$T\,(\text{Low}) = 0.693\,(R_B)\, C. \qquad (6)$$

From Equations 5 and 6:

$$T = T\,(\text{High}) + T\,(\text{Low}),$$

$$= 0.693\,(R_A + 2R_B)\, C, \qquad (7)$$

where T is the total period. Then,

$$F = 1 / T = 1.44 / (R_A + 2R_B)\, C, \qquad (8)$$

$$\text{Duty cycle (High)} = T\,(\text{High}) / T)$$

$$= (R_A + R_B) \;/ (R_A + 2R_B), \qquad (9)$$

$$\text{Duty cycle (Low)} = T\,(\text{Low}) / T)$$

$$= R_B / (R_A + 2R_B), \qquad (10)$$

where $R_A = R_{14}$ = 2,200Ω, $R_B = R_{15}$ = 2,2000 Ω and $C = C_8$ = 100nF. These values were chosen in order to provide an oscillator frequency of approximately 300Hz required to operate the sensor. From Eq. 4, the frequency output of the square wave, f_o = 311.69Hz. From Eq. 9, Duty cycle (High) = 52. 381%. From Eq. 10, Duty cycle (Low) = 47.62%. From Eq. 5, T (High) = 1.68ms. From Eq. 6, T (Low) = 1.52ms. These are illustrated in Fig. 4, respectively.

The oscillator output was set to +12V to guarantee a timed 12V swing on each positive half-square output portion of the waveform. The device can sink and source up to ±0.2A, and R_8 can have a minimum value of 12V/0.2A = 60Ω. A 1kΩ resistance limited the current's source and sink output to 12mA.

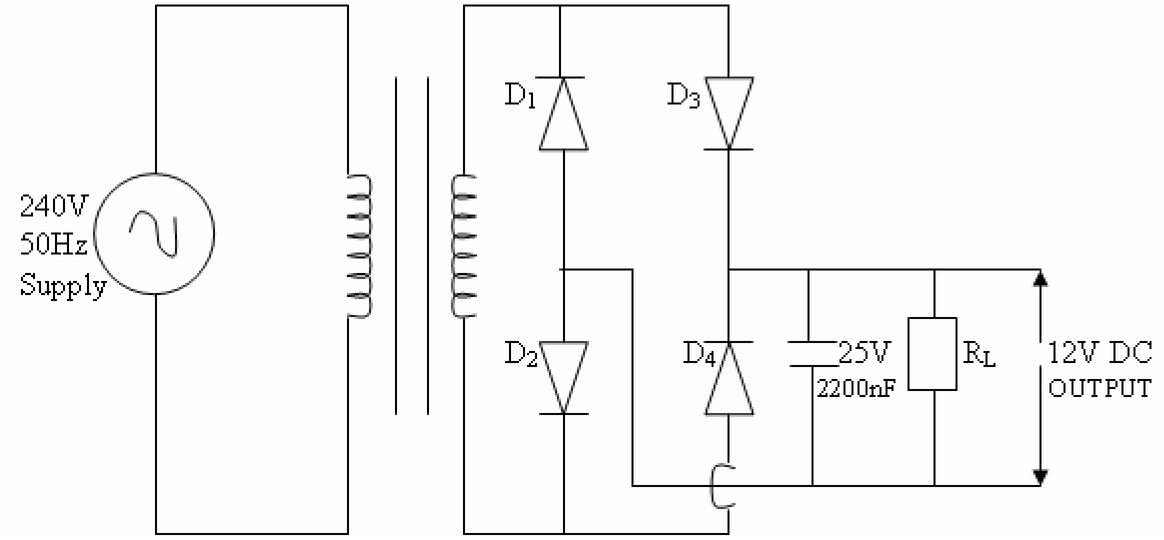

Fig. 2. The 12V *dc* regulated power supply.

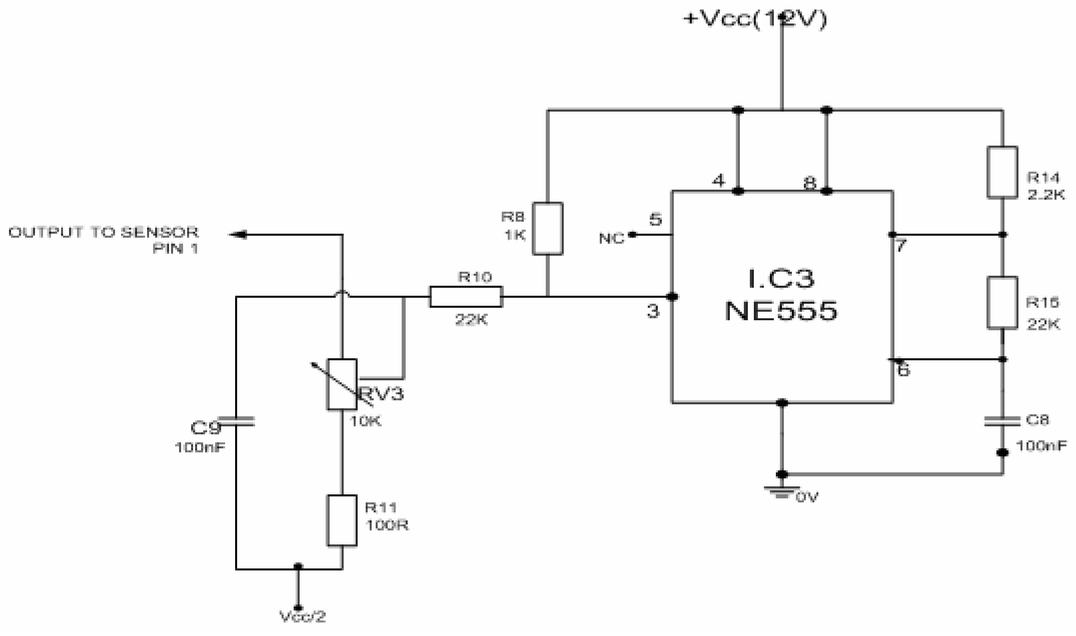

Fig. 3. The 555-based *ac* generator.

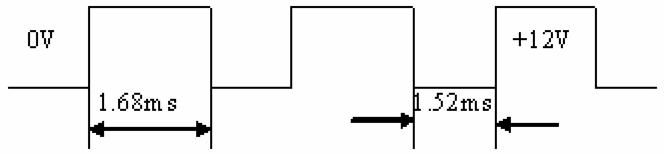

Fig. 4. Square wave output waveform.

Buffered Analogue $V_{cc}/2$ Reference Ground

This sub-circuit generated a buffered ($V_{cc}/2$) voltage source used as ground return for the entire circuit as shown in Fig. 5. The voltage at the non-inverting input of the op-amp (741) was calculated using the potential divider approach:

$$V_o = I \text{ x } R_2, \tag{11}$$

$$I = +V_{cc} / (R_1 + R_2)\,, \tag{12}$$

where R_1 = 47kΩ, V_{cc} = +12V, R_2 = 47kΩ. From Eq. 12, $I = 1.2766 \text{ x } 10^{-4}$ A. From Eq. 11, V_o = 6V.

Pin 6 of the op-amp was held at 6 volts, and used as ground return for the circuit. The output impedance of the potential divider approximately equals zero as the op-amp was wired with 100% negative feedback. This stabilizes the reference against variations when large currents are drawn. It also prevents current from the high-current side upsetting the operation of the low-current side as very negligible current now flows on the ground return.

Sensor / Buffer Module

The sensor used has three – pins with a large surface area for high degree of response and sensitivity. It was built around a H14DL resistive style humidity sensor. It has temperature compensation components in form of an integrated diode and a 1kΩ resistor as shown in Fig. 6. And powered by an ac voltage to prevent polarization of the sensor. Its output rides on a 50Hz, 6V *ac* generated by a 555-astable multivibrator circuit (Anon. 1993b, Paul 1995).

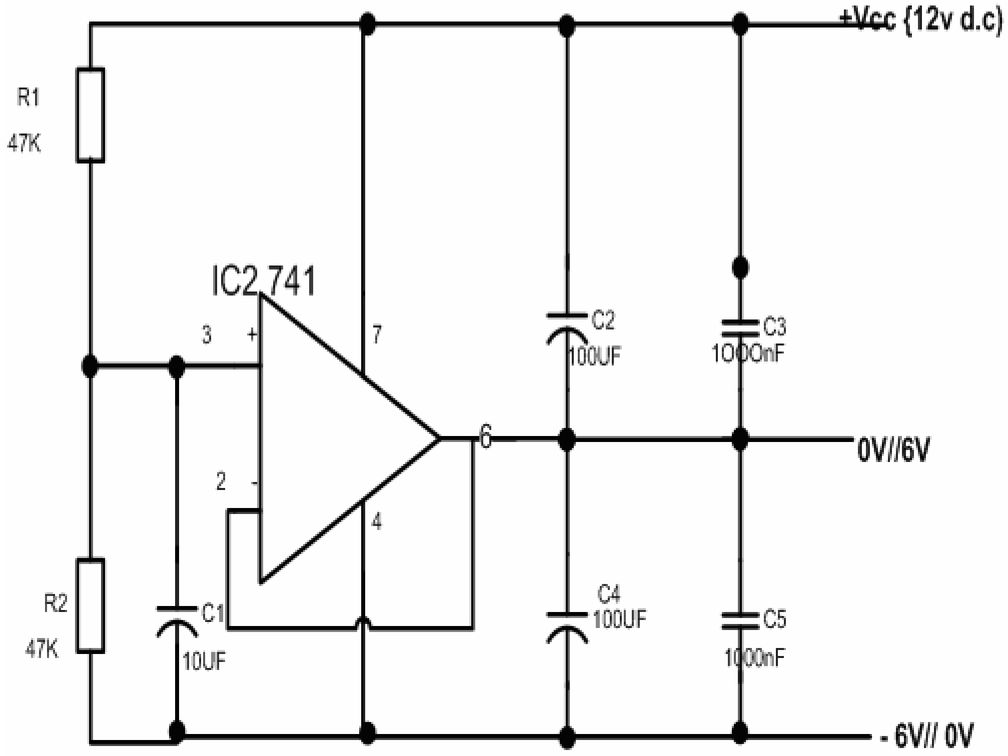

Fig. 5. The buffered $V_{cc}/2$ reference ground.

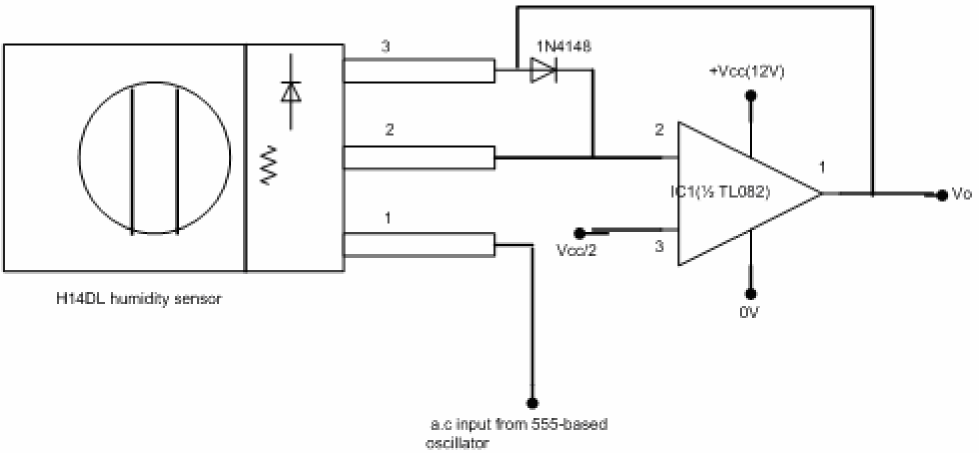

Fig. 6. The sensor/buffer module.

Precision Half-wave Rectifier / Amplifier

This active circuit as shown in Fig. 7 generated a half-wave rectified *dc* output that drives a meter. It has the second half of a TL082 dual operational amplifier connected to diodes D_2 and D_3 alongside other circuit components to capacitor C_7. A small value of 47µF was used for prompt response of the instantaneous input signal change from the sensor. The resistor values used in the analog ground generator sub-system held Pin 5 (Non-inverting input) at a potential of 6V. As the op-amp (TL082) was designed to run on a dual supply of $+/-V_{cc}$, a reference ground was generated by referring all points to 0V and the midpoint of the supply potential. The *ac* modulated output of the sensor and *dc* produced by the resistors R_3, RV_1, ZD_1 and R_4 network formed the two sources for the rectifier circuit. And the zener diode held the voltage output (V_o) at approximately 5.6 Volts.

$$R_s = (V_{in} - V_o)/ (I_o + I_d), \qquad (13)$$

where $R_s = R_3 = 470\Omega$, $V_{in} = +12v$, $V_o = +5.6V$. From Eq. 13, $I_o + I_d = 85mA$.

This gives an indication of the current flowing out of the node as shown in Fig. 8. To prevent erroneous results, RV_1 was adjusted to a value that forces the capacitor voltage towards zero in the absence of a sensor input. The active rectifier produces a rectified output of the *ac* input. During the positive half-cycle input, an amplified copy of the input positive peak appears as the op-amp output, charging C_7 up. When input polarities are reversed, a 100% feedback occurs through diode D_2. Thus, a very negligible negative output appears at the anode of D_3. (Anon. 1993b, Paul 1995). Here $R_5 = 22\text{k}\Omega$, $R_6 = 470\text{k}\Omega$, and

$$\text{Gain Av} = 470\text{K} / 22\text{ K} = 21.3636. \qquad (14)$$

C_7 charges up rapidly through 1kΩ resistance (R_{16}). The capacitor also discharges through a 471kΩ resistance. Since the charge/discharge times (0.033secs/15.34secs) are orders of several magnitudes apart, the capacitor holds the peak value of the output voltage with very little degradation in accuracy. The input continuously feds the output, and thus, C_7 has a value that continuously reflects the peak amplitude of the *ac* waveform amplified by the magnification constant.

Control (Schmitt Trigger) Output

A switched output control unit was used to drive an actuating mechanism via a relay. TR_1 and TR_2 are wired as Schmitt trigger control elements shown in Fig. 9.

The emitter of TR_1 was held at a potential of *V*cc/2 on a 12-Volt supply, and it's turned OFF until the base voltage (V_b) exceeds the emitter voltage, (V_e), at which point it becomes forward biased and the collector becomes LOW. TR_2 and its emitter are connected to +12V to maintain a very low collector–emitter voltage (V_{ce}). RV_2 was preset to that level of humidity at which the control output goes active. Above this level, TR_1 switches ON, activating TR_2 ON in effect. The potential at P_5 rises and feeds back the base of TR_1 via R_{18}, further driving TR_1 harder on. This snap-action effect is very desirable as it eliminates oscillation or jitter at the control output. Point 5 is a low to high *dc* output, suitable for driving the 12V *dc* relay. (Anon. 1993b).

Construction

The digital hygrometer circuit was constructed in accordance with the overall schematic circuit shown in Fig. 10. It was initially constructed on a bread board and finally transferred onto a Vero board. A simple and portable casing was constructed.

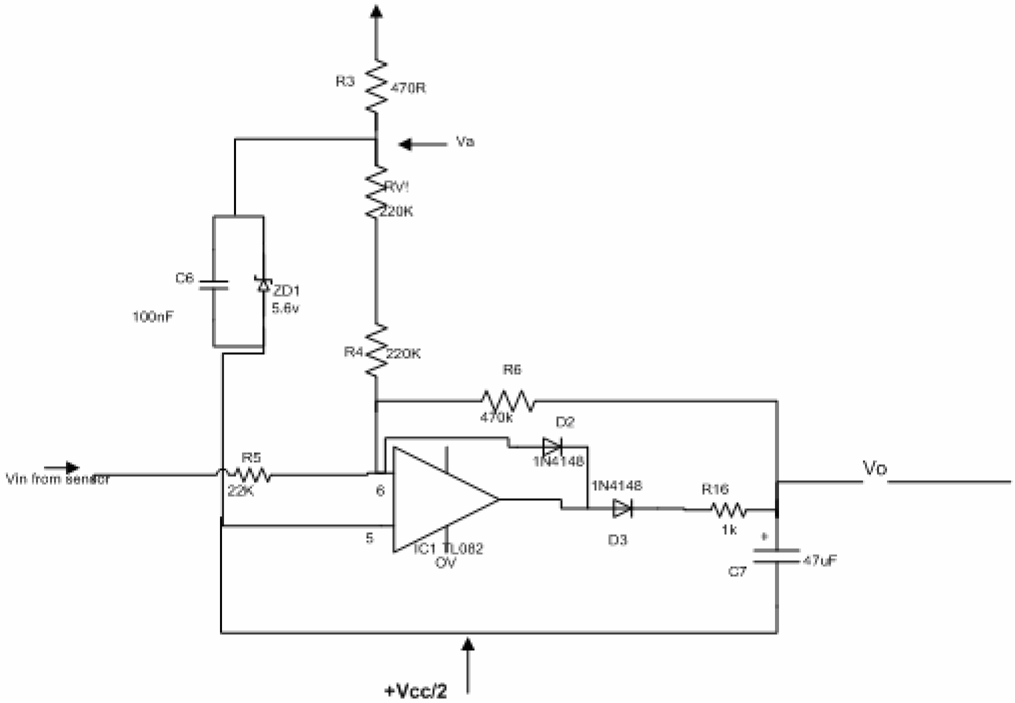

Fig. 7. Precision half-wave rectifier/amplifier sub circuit.

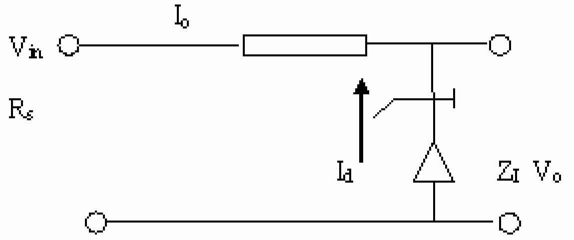

Fig. 8. An indication of the current flowing out of the node.

Testing

The testing of the entire project was carried out in three phases:

Phase1: The entire circuit on bread board was tested to ensure its functionality using a multi-meter. A steam generator was employed to test the sensor by varying the humidity level.

Phase 2: The entire circuit on a Vero board was also tested by measuring the outputs at the sensor stage and amplifier stage respectively. The input to the sensor was varied using a steam generator and an air drying machine. And at each stage the increase or decrease of the output was noted.

Phase 3 (calibration stage): A set of wet and dry bulb thermometers (Psychrometer) were used to provide a standard reference for the relative humidity (RH) and temperature readings respectively. The RH reading was taken at a room temperature of 25^0C and consequently, the electronic hygrometer output adjusted to correspond to the reference reading. Injected water vapour from boiling Kettle was used to increase the RH readings and subsequently the values from the thermometer and electronic hygrometer were noted. To decrease the RH, an air drying machine was used and the values of both meters noted. The calibration was repeated consecutively for a period of four days for efficiency of the device (Anon. 2006d; Abubakar 2006), see Figs. 11 and 12 in the Appendix.

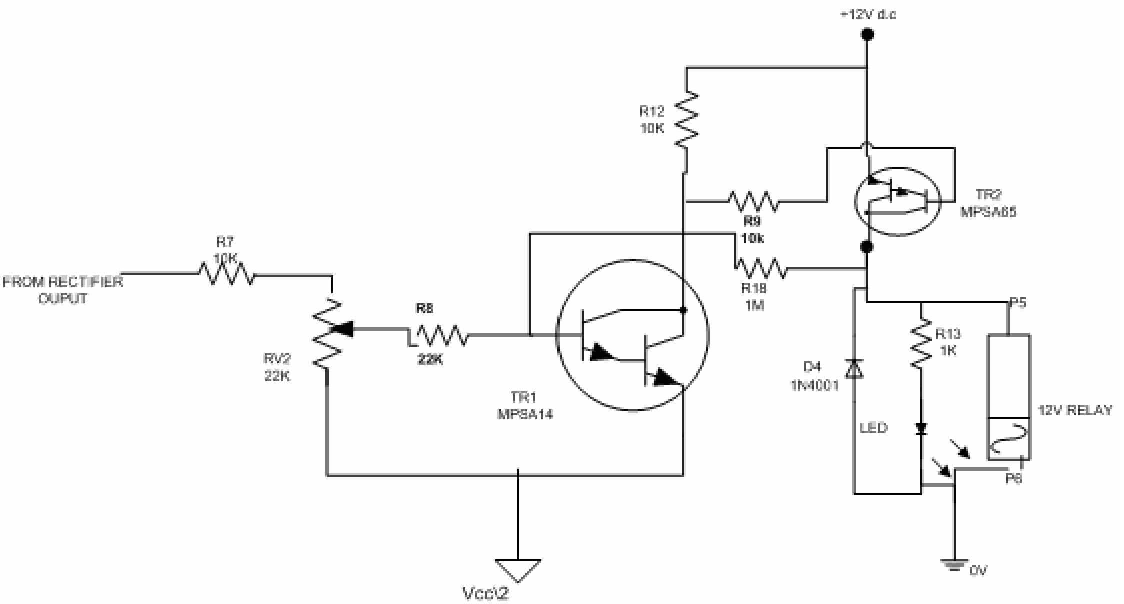

Fig. 9. The control (Schmitt trigger) output.

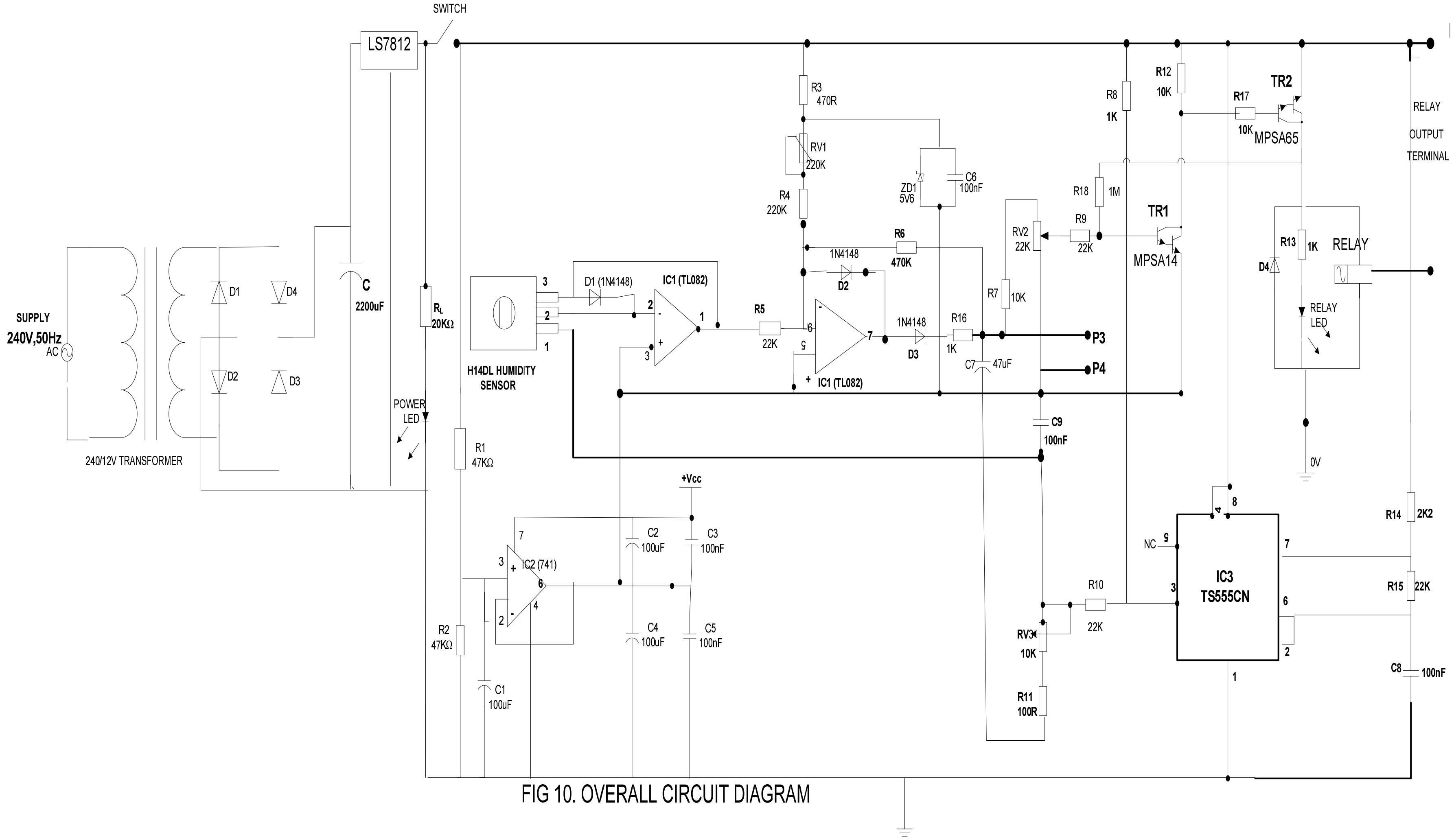

Fig. 10. Overall circuit diagram.

Results

The results are shown in Tables 1 and 2.

Discussion

The power supply and rectifier readings were satisfactory as reflected on Table 1. The frequency obtained from the *ac* generator compares favourably with the calculated value (311Hz). For the relative humidity readings obtained from both devices in Table 2 there were some slight variations. These variations were gradually reduced by daily re-calibration/adjustments. As it can be observed from Table 2, the variations in the readings from day one to the fourth day diminished significantly.

Table 1. Sub-units test results.

Sub-unit	Function	Test	Result
Power supply	Performance	Multimeter	Satisfactory
Rectifier	Voltage	“	Satisfactory
A.C generator	frequency	“	309Hz
Amplifier	Voltage signal	Gain	21.31

Table 2. Relative Humidity (RH) results.

Day	Psychrometer readings		Electronic hygrometer	Difference in RH (%)
	Dry-bulb temp.(^oC)	RH (%)		
1	25	82	79.00	3.0
2	27	67	66.00	1.0
3	29	67	66.50	0.5
4	26	71	70.70	0.30

Conclusion

The design and construction of a cheap, affordable and efficient electronic hygrometer system was successfully accomplished.

Recommendations

This work can be improved upon as follows:

The output can be digitized using a BCD to 7-segment decoder/ROM integrated circuit (74LS185). It could also be interfaced to a personal computer using a software program to display the result. Finally, to reduce the hysteresis effect during relay switching off, the solid state relay could be replaced with an electromagnetic one.

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Appendix

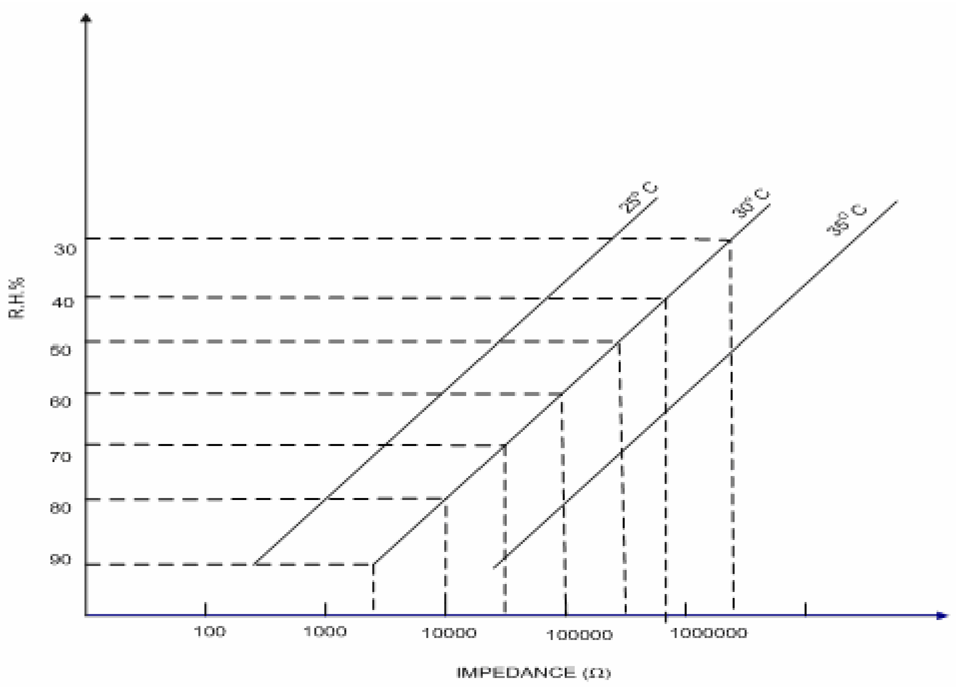
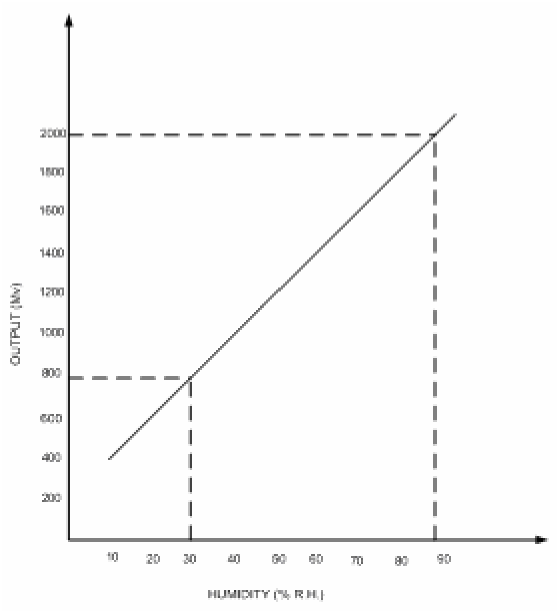


Fig. 11. Typical response of the H14DL sensor at different temperatures.



%RH	V_{output} (Mv)
20	630
30	800
40	970
50	1140
60	1310
70	1480
80	1650
90	1820
100	1990

Fig. 12. Typical response characteristic of the H14DL Sensor in a circuit with amplification of 20. (At 25 °C)