TEMPERATURE AND HUMIDITY MEASUREMENT INSTRUMENTATION BASED ON COLPITTS OSCILLATOR

A thesis
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Master of Science

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LETTER OF ORIGINALITY

This thesis is my design, and the all of references are written well.

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This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory. It is being submitted in partial fulfillment of the requirement for the degree of Master of Science in Instrumentation of Physics, Mathematic and Natural Science Faculty, University of Indonesia.

Depok, December 22th, 2008

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(Tony Mulia Ph.D)	**(Dr. Sastra Kusuma W.)**	**(Dr. BEF da Silva, M.Sc)**

Preface

Thanks to the Almighty, Allah, SWT, that always gives affection, blessing and everything that make me still alive and be able to finish this thesis. Thanks to my prophet Muhammad, S.A.W that all of his efforts, I find the truth of live, and take the best example of him to be a real people in this world.

In preparing this thesis, although it looks like very simple, I have been very conscious of many people lie behind this project. I need to thank not only to people who help me directly but also to many people who help me become a scholar and people can do such this thesis.

First and foremost I thank my **MOM**, who raised me not only with the utmost love and intellectual and material support but also with the basic values that I have proudly made my own. I would also like to thank her for the faith and patience with which she supported even those of my life decisions that did not fit her own visions and hopes of the best possible life for me.

I am especially grateful for the care, love, and affirmation given me by my sisters. They have not only been loving siblings but also emotional and intellectual guiding lights throughout my life. They also had the good sense to marry people just as wonderful as themselves, who have helped me in so many ways. My loving nieces and nephews are also essential parts of this family without whom I would be nothing. I am very happy to be a part of *the best family* in the world.

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Mbk Pur, the most beautiful in our group. Hope the God bless us forever and the friendship will not be end.

I will happily receive all critics, support and suggestion which have correlated with this thesis by my email to: mr_khairul_amri@yahoo.co.id or mr.khairul.amri@gmail.com. Hope this can give little contribution for developing knowledge in Indonesia.

Jakarta, December 2008

Khairul amri

ABSTRACT

TEMPERATURE AND HUMIDITY MEASUREMENT INSTRUMENTATION BASED ON COLPITTS OSCILLATOR

Khairul Amri

Instrumentation of Physics

This thesis is designed to get the instrumentation with high sensitivity. Generally, this thesis presents several noteworthy characteristics. First, Colpitts oscillator is used as measurement instrumentation for temperature and humidity with frequency output varying which correlate with those parameters. Second, AT-Tiny2313-20PU is employed as frequency counter interfaced to a computer through an RS-232 port. Third, LabVIEW is employed as the software development environment to communicate from computer to external hardware for automatically uploading and processing data. The increasing sensitivity gotten is from (29,9exp$^{-3,45E-2T}$) $\Omega/^{0}C$ to (-9,73E4/T)Hz/^{0}C and from (1,83E-9) F/%RH to (-48,3E2)Hz/%RH for temperature and humidity respectively.

Key words – Colpitts oscillator, frequency counter, temperature, humidity, measurement instrumentation

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Chapter 1

Introduction

1.1. Background

Nowadays, we are witnessing the rapid explosion of knowledge and technology. All researchers all over the world compete to create innovation and make everything more efficient and effective especially used to welfare the humanity. A high accuracy of measurements is necessary for successful starting and performances of all researchers. Because data of measuring result is very important, it should be high resolution, span and accuracy. On the other hand, calculation of the data must be representative up to date and displayed easily.

Temperature and humidity, called meteorology parameters, determine a large extent of how comfortable an environment for human, animals and plants could be. There are many good, which can only be preserved in a suitable environmental condition. The atmosphere is never perfectly dry. There is always a certain amount of water vapor presents in the air. Besides that, both of them also influence other physical variables, thus measuring, the influences of temperature and humidity always follow advanced researches. On the other hand, temperature and humidity are very important for the operation and/or automatic controls in many industrial processes.

There are many kinds of sensors that can be used to measure temperature and humidity. Several of them are IC LM 35, thermocouple, Thermistors etc for temperature sensor, SHT 11, SK, capacitive and resistive humidity sensor for humidity sensor. Generally, the outputs of the sensors are current, voltage or resistance form. The signal conditioning from those output are effortless to be interfaced to an electronic circuit but they are less sensitive.

Many applications require variable frequency operations to use in synthesizers where a range of frequencies or frequency steps may be needed across a particular band of frequency. The variance of frequency output can be used as an output sensor. If the frequency can be modulated up into 1 MHz and the smallest of it can be detected into 1 Hz, the relative chance of the frequency is

10^{-6}, so the frequency is more sensitive than others e.g. current, resistance, and voltage. In order to achieve such variations, one of resonator components in oscillator circuit can be replaced by sensors which can be varied by physical parameters. There are many types of oscillator. They are generally classified according to the frequency determining components. The three classifications are RC, LC, and crystal oscillator. The advantages and disadvantages between three oscillators are displayed on Table 1 [1].

Table 1. Comparison of all oscillator types

Types of oscillator	Advantages	Disadvantages
RC oscillator (Phase-shift, Wien bridge)	1. It is useful at low frequency 2. Its output frequency is more stable than LC oscillator 3. It does not required inductor	1. It is not suited for variable frequency 2. It is more susceptible to phase noise than LC oscillator 3. The circuit gives small output 4. It is difficult for circuit to start oscillation because of small feedback
LC oscillator (Colpitts, Hartley)	1. It is usable for variable frequency 2. It is useful at high frequency 3. It has high phase stability	1. It is expensive for low frequency 2. The frequency output is unstable
Crystal oscillator	It is very stable	It cannot be employed as variable oscillator

Based on the Table 1, LC oscillator is eligible choice to be used as measurement purpose because its frequency output is easily varied. From both types of LC oscillator, Colpitts oscillator provides better frequency stability than Hartley, while the range of frequency output from Colpitts is wider than Hartley [1]. So, the goal of this research is to design temperature and humidity measurement instrumentation based on the oscillator Colpitts. Doe to the output of this sensor is frequency; Microcontroller is employed as frequency counter. It is not only can directly measure the output frequency from sensors but also can reduce operational cost because of small sized, low power that collect detailed information about the physical environment with a few instructions.

1.2 Purposes of the Project

The several aims of this project are:

1. Designing and creating the oscillator Colpitts as temperature and humidity measurement tools.
2. Improving the sensitivity of temperature and humidity sensors by Colpitts oscillator circuits.
3. Making software to do signal processing, save and display data by real time.

1.3 Advantages of the Project

This project can be used as a basic example in measurement system to get instrumentation with high sensitivity and low-cost. Frequency measurement is one of the best choices to improve the sensitivity of measurement instrumentation.

1.4 Restrictions on the Project

The restrictions of this project consist of architecture design, software design, recording data, and visualization of measurement data that are clearly described in detail.

Chapter 2
Theoretical Background

2.1 Oscillator Colpitts

An oscillator or an electronic generator is a circuit that can generate a frequency source (a steady state time varying signal) with constant input signal (dc power-supply, battery)[2]. An oscillator is fundamentally a combination of an amplifier and a resonator that selects a part of an amplifier output and returns it to the amplifier input. On the other word, resonator is the frequency selective component. A generalized depiction of such an oscillator is displayed on Figure 2.1. On the other hand, the gain applied at low signal amplitude will be increased until the output amplitude reaches some constant value.

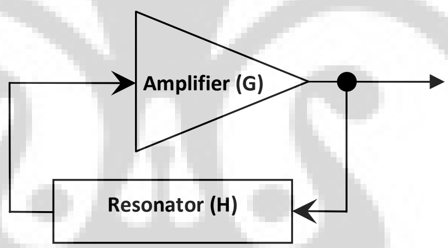


Fig. 2.1 The main components of an oscillator

There are several kinds of oscillator. Several of them are Colpitts, Hartley, Pierce, etc. In this thesis, I use Colpitts oscillator because it is suited to variable frequency usage, higher oscillation frequency from 1 Hz up to 1 GHz, one of the simplest structure (one transistor, one inductor and two capacitors), high phase stability, low noise, and low power application, doe to the simplicity and the high negative conductance of the oscillator core [1]. The Colpitts uses a capacitor tap. The tapping is provided by series of combination of the two capacitors which are in parallel with the resonator. The simplest Colpitts resonators consist of at least two elements; inductor and capacitor, but in this project, I use resistor, capacitor and inductor as resonator components.

The Colpitts oscillator can be found in common base and common collector formats as well as the common base type. One of Colpitts oscillators form in common collector circuit is presented in Figure 2.2.

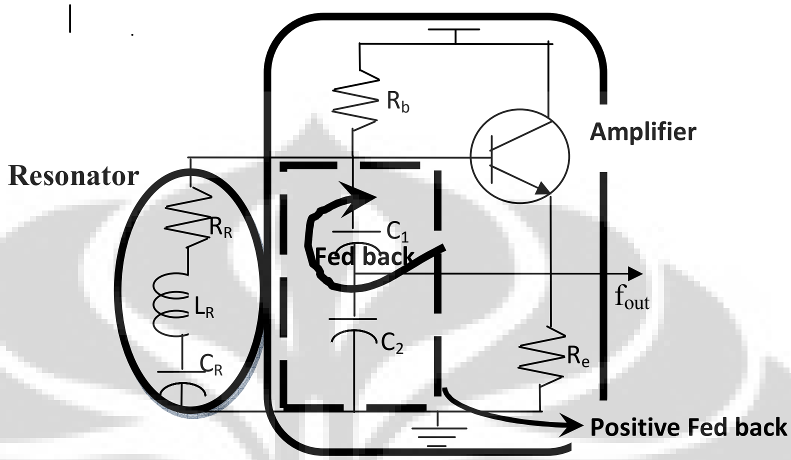


Fig. 2.2 Circuit diagram of experimental Colpitts oscillator

2.1.1 The Operating Point of Transistor as Amplifier

The bipolar transistor is used as a device that is capable of producing gain at the oscillation frequency. Every amplifier has a dc and an ac equivalent circuit. Because of this, it has two load lines: a dc and an ac load line. For a small-signal operation, the location of Q the point is not critical. But with large signal amplifiers, the Q point has to be at the middle of the ac load line to get the maximum possible output swing [3].

One way to move the Q point of dc load line from Figure 2.3 is by varying the value of R_b and R_e shown in Figure 2.2. To get a maximum peak-to-peak unclipped output, the Q point must be at the middle of the ac load line.

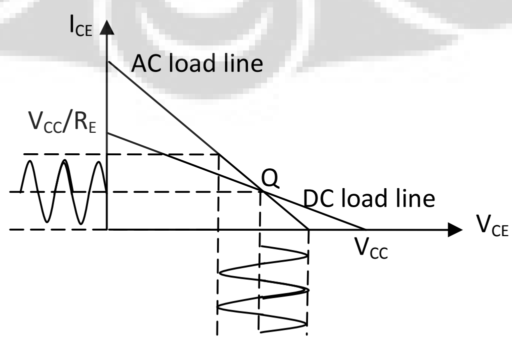


Fig. 2.3 AC and DC load line

2.1.2 Oscillating Condition

An amplifier and an oscillator as a component of oscillator contain real and imaginer impedance. In order to get an oscillation, two conditions must be met. Both of conditions are:

1. Amplitude condition : $R_A + R_R < =0$

   where: R_A = real impedance of amplifier

   R_R = real impedance of resonator

   To be able to generate a signal, a total impedance of oscillator must be less and/or equal to zero, or we said that a negative resistance of oscillator. If the prerequisite condition can't be fulfill, the output signal will be decay because of an overdamp. The loop power gain must be equal to unity or [A.H]=1; where A network is the complex amplifier part, and H network is frequency determining part. When the oscillation start up, the amplification of signal [A.H] must be higher than 1. The signal will be built up until clipping or stability occurs because of saturation and cutoff. The amplification will decrease into unity when the stability has been reached.

2. Phase condition : $X_A + X_R = 0$

   where: X_A= imaginer impedance of amplifier

   X_R= imaginer impedance of resonator

   The loop phase shift must be 0, 2π, 4π, and so on…

   On the emitter follower (common collector), the output and an input signal have the same in phase, so to get a positive feedback, the output can be directly connected to the input. Total imaginer impedance that must be equal to zero gotten by combining of capacitors and inductors in an oscillator.

2.1.3 Feedback

Positive feedback is the most important requisite for oscillation**.** Positive feedback is accomplished by adding part of the output signal in phase with the input signal. Positive feedback is used to reinforce energy that has been lost as long as oscillation or we can say that feedback is use to sustain oscillation. In some cases, for the circuit to oscillate, the feedback signal must be in phase with the input signal. Since the input and output signals in common collector are in phase, i need only couple part of the output signal back to the input. From Figure 2.2, capacitor network of C_1 and C_2 would provide positive feedback from the emitor to the base of the transistor.

2.1.4 Negative Resistance

For optimum performance, an oscillator circuit has to be designed in such a way as "negative resistance" which is sometimes called the "oscillation allowance". Negative resistance (or negative differential resistance (NDR) or differential negative resistance (DNR)) is a condition where the current falls as the voltage is increased or voltage falls as the current is increased vice versa. This phenomenon is shown in Figure 2.4.

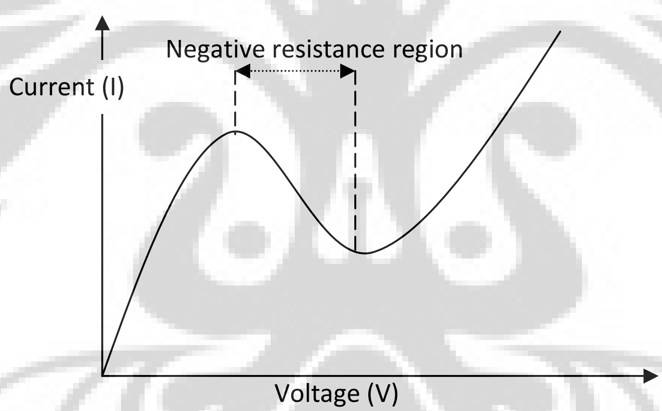


Fig. 2.4 Current versus Voltage on negative resistance material

To show the negative resistance which presents on Colpitts oscillator, its schematic diagram can be simplified to Figure 2.5.

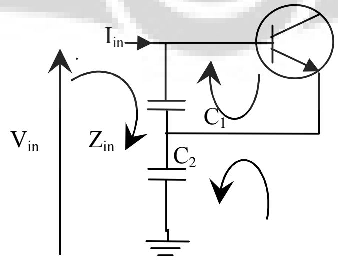


Fig. 2.5 Simplified schematic diagram showing the reflection amplifier part of the Colpitts oscillator

From the three loops, equations resulted are:

$$V_{in} = I_{in}(X_{C1} + X_{C1}) - I_b(X_{C1} - \beta X_{C2}) \quad (2.1)$$

$$0 = -I_{in}(X_{C1}) + I_b(X_{C1} + hie) \quad (2.2)$$

Rearrange to give I_b from Equation (2.2) and sub into Equation (2.1) where is:

$$I_b = \frac{I_{in}X_{C1}}{(X_{C1}+hie)}$$

So $$\frac{V_{in}}{I_{in}} = Z_{in} = \frac{hie(X_{C1}+X_{C2})+X_{C1}X_{C2}(1+\beta)}{X_{C1}+hie} \quad (2.3)$$

If we assume that $X_{C1} << hie$ than :

$$\frac{V_{in}}{I_{in}} = Z_{in} = -\left(\frac{1+\beta}{hie\cdot\omega^2 C_1 C_2}\right) + \left(\frac{1}{j\omega[C_1C_2/(C_1+C_2)]}\right) \quad (2.4)$$

Equation 2.4 shows that Colpitts oscillator contains a negative resistance. The purpose to count the negative resistance is just to find the positive coefficient that should be less than negative resistance. Since I use Thermistors which has positive resistance, the selectivity of resistance range of sensor must be less than negative resistance of Colpitts oscillator to work properly. If total of resistance higher than 0, the oscillation will overdamp.

2.1.5 Colpitts Circuit Analysis

To simplify the analysis, the schematic of Colpitts oscillator used in this project can be changed into general schematic of oscillator which is depicted in Fig. 2.6.

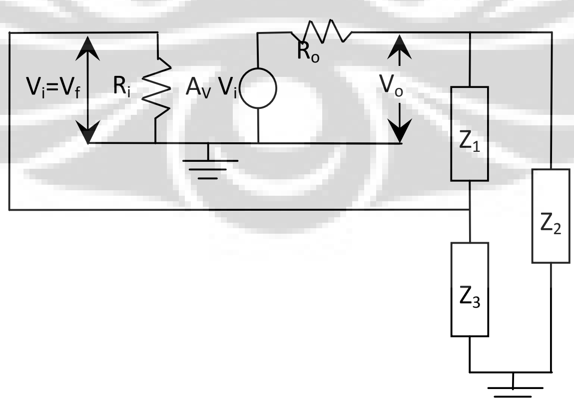


Fig. 2.6 General equivalent circuit of oscillator

$$RLC\ series\ as\ a\ resonator\{Z_3 = R_R + i\left(\omega L_R - \frac{1}{\omega C_R}\right) = R_R + iX_3 \quad (2.5)$$

$$positive\ fed\ back\ capasitors \begin{cases} Z_1 = {}^{i}/_{-\omega C_1} = iX_1 \\ Z_2 = {}^{i}/_{-\omega C_2} = iX_2 \end{cases} \tag{2.6}$$

The load impedance Z_L consists of Z_2 parallel with the series combination of Z_1 and Z_3.

$$Z_L = \frac{Z_2(Z_1+Z_3)}{Z_1+Z_2+Z_3} \tag{2.7}$$

Output voltage :

$$V_0 = A_v V_i \frac{Z_L}{Z_L+R_0}$$

$$\frac{V_0}{V_i} = A_v \frac{Z_L}{Z_L+R_0}$$

So, the complex gain without feedback:

$$\mathrm{A}= \frac{V_0}{V_i} = \frac{A_v Z_L}{Z_L+R_0} \tag{2.8}$$

the complex feedback

$$\mathrm{H}= \frac{Z_3}{Z_1+Z_3} \tag{2.9}$$

so, the complex loop gain:

$$A.H = A_v \frac{Z_3 Z_2}{R_0(Z_1+Z_2+Z_3)+Z_2(Z_1+Z_3)} \tag{2.10}$$

Equations (2.8) and (2.9) sub into Equation (2.10):

$$\mathrm{A}.H = A_v \frac{Re+Img}{\left[-X_2(X_1+X_3)+R_0R_q\right]^2+\left[X_2R_q+R_0(X_1+X_2+X_3)\right]^2} \tag{2.11}$$

where:

$$Re = X_1X_2^2X_3 + X_2^2X_3^2 + R_R^2X_2^2 + R_OR_RX_1X_2 + R_OR_RX_2^2$$

$$Img = (-R_RX_1X_2^2 + R_OR_R^2X_2 + R_OX_1X_2X_3 + R_OX_2^2X_3 + R_OX_2X_3^2)i$$

On the sub Chapter 2.1.3, it has been already explained that in oscillation, the phase shift should be zero. It means that the complex loop gain does not have the imaginer condition; *Img=0*. So,

$$\left[-\frac{R_0L_R^2}{C_2}\right]\omega^4 + \left[-\frac{R_0R_R^2}{C_2} + \frac{R_0L_R}{C_2^2} + \frac{R_0L_R}{C_1C_2} + \frac{2R_0L_R}{C_2C_R}\right]\omega^2 - \left[\frac{R_0}{C_2^2C_R} + \frac{R_0}{C_1C_2C_R} + \frac{R_0}{C_2C_R^2} - \frac{R_R}{C_1C_2^2}\right] = 0 \tag{2.12}$$

A *biquadratic Equation* is the special case of the quartic equation containing no odd degree terms, where a, b, c are known real or complex numbers and a≠0 [3].

$$ax^4 + bx^2 + c = 0 \qquad (2.13)$$

The four roots of biquadratic are:

$$r_1, r_2, r_3, r_4 = \pm\sqrt{\frac{-b\pm\sqrt{b^2-4ac}}{2a}}$$

By using the biquartic formula which has a positive and maximum root (the most stable frequency), the frequency of oscillator Colpitts is:

$$f = \frac{1}{2\pi}\sqrt{\frac{-b-\sqrt{b^2-4ac}}{2a}} \qquad (2.14)$$

where:

$$a = \left[-\frac{R_0L_R^2}{C_2}\right]$$

$$b = \left[-\frac{R_0R_R^2}{C_2} + \frac{R_0L_R}{C_2^2} + \frac{R_0L_R}{C_1C_2} + \frac{2R_0L_R}{C_2C_R}\right]$$

$$c = \left[\frac{R_0}{C_2^2C_R} + \frac{R_0}{C_1C_2C_R} + \frac{R_0}{C_2C_R^2} - \frac{R_R}{C_1C_2^2}\right]$$

Equation 2.14 elaborates that frequency of the Colpitts oscillator depends on resistance resonator, R_R, capacitance resonator, C_R, inductor resonator, L_R, C_1, C_2, and output impedance R_0 of the amplifier.

2.1.6 Transfer Function of Instrumentation

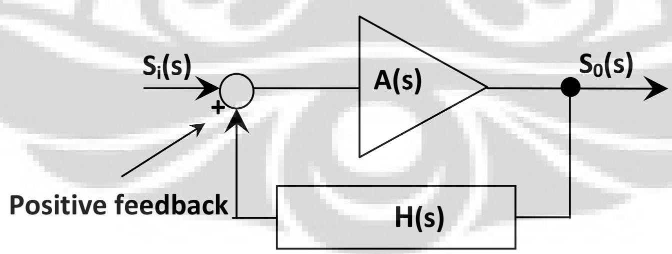


Fig. 2.7 The classical feedback system

From the Figure 2.7, the general form of positive feedback is:

$$\frac{S_0(s)}{S_i(s)} = \frac{A(s)}{1-H(s)A(s)} \qquad (2.15)$$

Where:

$S_o(s)$ = output function   A(s) = complex gain

$S_i(s)$ = input function H(s) = complex feedback

Equations (2.8) and (2.9) sub into Equation (2.15):

(2.16)

Equation (2.5) and (2.6) sub into Equation (2.16) and the jω is changed with s:

(2.17)

If the value of Colpitts components insert into 2.17, the gain and phase performance of the temperature and humidity measurement instrumentation is figure out in Figure 2.8

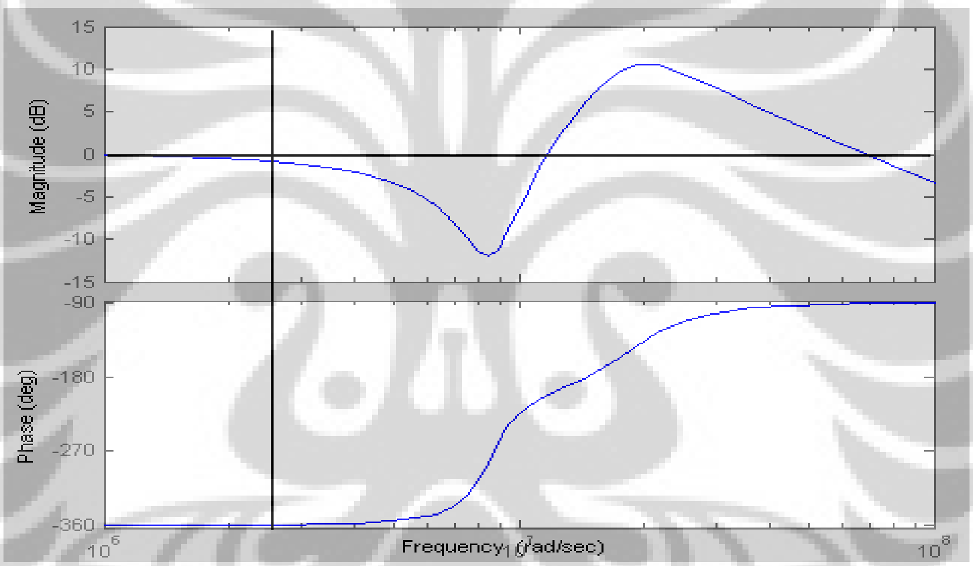


Figure 2.8. Gain and phase performance of instrumentation

Figure 2.8 shows the gain of system from 1 MHz to 1,5 MHz is one while the output phase from 1 MHz to 4 Hz are the same or multiplied of 2π with input phase. Those conditions fulfill the requisites of oscillation.

2.2 Temperature, Humidity and Their Relationship

2.2.1 Temperature

Temperature is one of the most important parameters in process control and the most widely sensed of all variables. Temperature is defined as a specific degree of hotness or coldness as referenced to a specific scale. It can also be defined as the amount of heat energy in an object or system. Heat energy is directly related to molecular energy (vibration, friction and oscillation of particles within a molecule): the higher the heat energy, the greater the molecular energy [5].

The unit of the fundamental physical quantity known as the thermodynamic temperature (unit T) is the Kelvin, symbol K, defined as the fraction 1/273.15 of the thermodynamic temperature of the triple point of water. Most people think in terms of degrees Celsius. The relation between Kelvin and Celsius is:

$$T = X\,^{0}C + 273.15 \quad (2.18)$$

From Equation 2.18, it is clear that the triple point of water in degrees Celsius is 0.01 ^{0}C. From a practical point of view, the ice point is 0^{0} C and the steam point 100 ^{0}C.

Accurate measurement of the temperature is not easy and to obtain accuracies better than 0,1 ^{0}C great care is needed. Errors occur due to several sources, such as the sensor non-linearity, temperature gradients, calibration errors, and poor thermal contact.

2.2.2 Humidity

Humidity is the amount of water vapor in a sample of air compared with the maximum amount of water vapor the air can hold at any specific temperature. The four types of humidity expression are absolute humidity, mixing ratio/humidity ratio, relative humidity and specific humidity [5].

Absolute humidity is the quantity of water (m_w) in a particular volume of air (V_a). The most common units are grams per cubic meter, although any mass unit and any volume unit could be used. Absolute humidity called vapor density is formulated with

$$AH = \frac{m_w}{V_a} \quad (2.19)$$

However, absolute humidity changes as air pressure changes, although the quantity of water doesn’t change. Its matter causes the difficulty to observe this value.

Mixing of Humidity ratio is expressed as a ratio of kilograms of water vapor, m_w, per kilogram of dry air, m_d, at a given pressure. The colloquial term

Moisture Content is also used instead of Mixing/Humidity Ratio. Humidity Ratio is a standard axis on psychometric charts, and is a useful parameter in psychometrics calculations because it does not change with temperature except when the air-cools below dew point

That ratio can be expressed as :

$$MRi = \frac{m_w}{m_d} \tag{2.20}$$

Relative humidity is defined as the ratio of the partial pressure of water vapor in a gasses mixture of air and water vapor to the saturated vapor pressure of water at a given temperature. Relative humidity is expressed as a percentage and is calculated in the following manner:

$$RH = \frac{P(H_2O)}{P^*(H_2O)} \times 100\% \tag{2.21}$$

where:

$P(H_2O)$ = partial pressure of water vapor in the gas mixture

$P^*(H_2O)$= saturated vapor pressure of water at the temperature of gas mixture

RH = relative humidity of the gas mixture

Relative humidity is the most commonly used to express the humidity because not only easy to observe but also constant value with pressure change.

Specific humidity is the ratio of water vapor to air (dry air plus water vapor) in a particular volume of air. Specific humidity ratio is expressed as a ratio of kilograms of water vapor, m_w, per kilogram of air, m_a. That ratio can be given as:

$$SH = \frac{m_w}{m_a} \tag{2.22}$$

2.2.3 Relationship between Temperature and Humidity

Relative humidity is depend on temperature but the changing humidity *almost* does not influence temperature. To make the water evaporate, we added heat, which was absorbed by the individual molecules of water. As each molecule absorbs heat, it gets more energetic, and eventually, has so much energy that it breaks the hydrogen bonds holding it to the other water molecules, leaves the liquid water, and floats off on its own, as a molecule of water vapor.

At a higher temperature, more water vapor will present in the air. This is a general rule about relationship between temperature and humidity: the higher the air temperature, the more water vapor will be present in the air at saturation. Term of saturation refers to the maximum amount of water that can be present as a vapor in the atmosphere at one temperature [1]. The comparison between amount of water in air at 100% and 50% of relative humidity across a range of temperature from 0 to 50^{0}C is depicted in Figure 2.9.

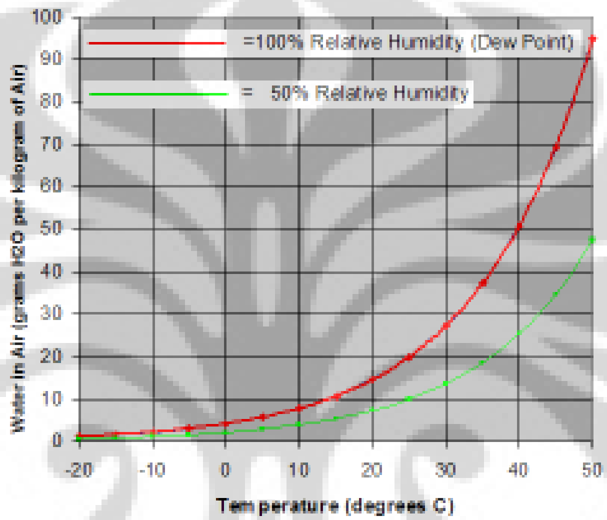


Fig. 2.9 Amount of water in air versus temperature on 50 and 100 % of RH [2]

2.3 Temperature and Humidity Sensors

Sensor is a device that responds to a physical property and converts one form of energy into another with no regard to efficiency, and is used to measurement purposes [6].

There are many types of sensors to measure temperature. Thermistors (thermally sensitive resistors) are one of the older classical sensors and still used extensively due to their big advantages. In this research, Thermistors shown in Figure 2.10 is used as temperature sensor. They typically consist of a combination of two or three metal oxides that are sintered in a ceramic base material and have lead wires soldered to a semiconductor wafer or chip, which are covered with epoxy or glass [6].

Fig. 2.10 Thermistors [11]

Thermistors has a large changeable resistance versus temperature. If the resistance changes, so does the frequency output from Colpitts oscillator. Thermistors is used in low to medium temperature applications, ranging from -50^{0}C to +200^{0}C. It is a low cost and its accuracy is up to +0.2^{0}C. It also responses fast and is small sized.

Thermistors are generally available in two types: Negative Temperature Coefficient (NTC) Thermistors, and Positive Temperature Coefficient (PTC) Thermistors. PTC Thermistors are generally used in power circuits for in-rush current protection. These devices are usually used in switching applications from limit currents to safe levels.

NTC Thermistors employed in this research exhibit many desirable features for temperature measurement and control. Their electrical resistance decreases with increasing temperature (Figure 2.11) and the resistance-temperature relationship is very non-linear. Depending upon the type of material used and the method of fabrication [6].

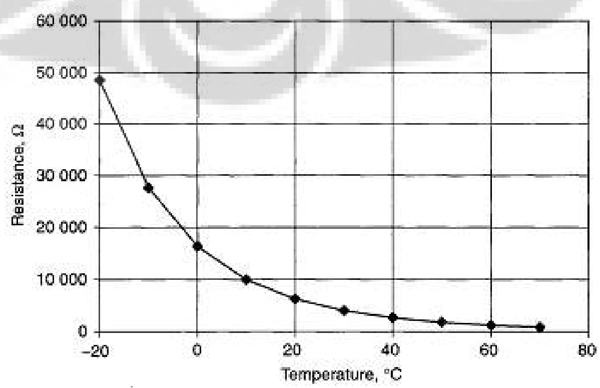


Fig. 2.11 Relationship between the resistance of NTC Thermistors with Temperature [6]

The most common humidity sensors are capacitive, resistive, and thermal conductivity. We just elaborate about the capacitance RH sensors because these sensors are used in this research. They dominate both atmospheric and process measurements and are the only types of full-range RH measuring devices capable of operating accurately down to 0% RH. Because of their low temperature effect, they are often used over wide temperature ranges without active temperature compensation.

In a capacitive RH sensor, the change in dielectric constant is almost directly proportional to relative humidity in the environment. Typical specifications of RH sensors which are used are described in Table 2.

Table 2. Characteristic of capacitive humidity sensor [11]

No	Parameters	Value
1	Operation range	0~100% RH
2	Operation Voltage	<12 VDC
3	Typical capacitance	105pF±5% at 33%RH
4	Capacitance change	2.4pf / 10 %RH
5	Hysteresis	< 2 %RH
6	Linearity	± 1 %RH (10~90%RH)
7	Operating temperature range	- 40 °C ~ +60 °C
8	Storage condition	0~95 %RH, -20 ~ +50 °C

This sensor has low temperature coefficient and can function at temperatures up to 60°C. It is able to fully recover from condensation and resist chemical vapors. Response time ranges from 30 to 60 seconds for a 63% RH step change [11].

Capacitive RH sensors are usually analyzed by converting their capacitance into another physical, frequency, voltage, etc. Especially for this research, the variance of frequency output can be directly created by adding the variable capacitance into the resonator in Colpitts oscillator.

The capacitance of a capacitor can be calculated on the basis of its structure as Equation 2.23.

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d} \quad (2.23)$$

Where ε_o is the dielectric constant of free space, ε_r is the dielectric constant of the material, A is the usable plate area, and *d* is the distance between the two electrodes.

Most capacitive sensors can be divided into two classes: those in which the plate area (geometry) changes (i.e. level sensors or displacement sensors), and those that rely on a change in ε_r (i.e. proximity or moisture sensors). Classic examples of dielectric sensors are moisture sensors, which use a moisture sensitive polymer layer as the dielectric (Figure 2.12). With increasing moisture, more and more water molecules are deposited, so that ε_r increases. Therefore, the capacitive sensor is effectively used as moisture sensor.

Fig. 2.12 Capacitive humidity sensors [11]

2.4 Microcontroller

Microcontroller is the IC that contains CPU (Central Processing Unit), few I/O, program memory, RAM (for storing variables) and other supporting components which are used for data acquisition and control applications. It can interface to motors, a variety of displays as output devices, communicate to PCs, read external sensor values, even connect to a network of similar controllers, and executes all that with a minimum of extra components [7].

In this research, I use ATtiny2313-20PU. The ATtiny2313 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC (Reduced Instruction Set Computer) processor with a Harvard architecture. In RISC processor, registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The result of this architecture is more code efficient while achieving throughout up to ten times faster than conventional CISC (Complex Instruction Set Computer) microcontrollers. By executing powerful instructions in a single clock cycle, the ATtiny2313 achieves throughout approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

The ATtiny2313 provides the following features: 2K bytes of In-System Programmable Flash, 128 bytes EEPROM, 128 bytes SRAM, 18 I/O, two flexible Timer/Counters, internal and external interrupts, a serial programmable USART, and programmable Watchdog Timer with internal Oscillator. The Idle mode stops the CPU while allowing the SRAM, Timer/Counters, and interrupting system to function continuously. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next interrupt or hardware reset. In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption [4].

The ATtiny2313 which can operate up to 20 MHz from 2,7 V until 5,5V will be programmed with BASCOM for easily working of designer. Among several components known, only two components of ATtiny2313 will be clearly described. They are Timer/Counter and Serial communication because only of them that will be used in this project.

2.4.1 Timer/Counter

ATtiny2313 has one timer/counter 8-bit and one timer/counter 16-bit with separated prescaler. The timer can be functioned as a timer or a counter. As a timer, the internal clock signal or a derivative of that clock signal is used up to clock the timer. The clock signal can be selected by the size of prescaler. As a counter, an external signal on a port pin (T1) is used to clock the timer/counter. To ensure proper sampling of the external clock, the minimum time between two external clock transitions must be at least one internal CPU clock period. The external clock signal is sampled on the rising/falling edge of the internal CPU clock. The highest CPU clock, the highest external clock can be counted.

After the timer/counter overflows, it resets to $00 and the Timer/counter Interrupt Flag Register (TIFR) will be set, there after continued counting up.

2.4.2 Serial Communication

RS-232 communication is by far the most common communicating mode that the ATtiny2313 can utilize. RS-232 is an asynchronous serial transfer mechanism. This bit-serial transmission method can be split up in two parts; those in which the original byte data is split up serially for transmission and those in which this serial data is physically transmitted over wires. The order of its transmission is LSB of the data byte first and MSB of the data byte last.

The transmitter and receiver of data use a fixed data rate, called the bit rate. Most common bit rates are 300, 600, 1200, 1800, 2000, 2400, 4800, 9600 and 19200 bits per second. Bit rate is the time for which one bit (out of the 10 or so bits) is available at the output (or input).

The bit data to be transmitted is converted to RS-232 standard voltage level before putting it on the wires. RS-232 defines a mark (on) bit as a voltage between -3V and -12 and a space (off) bit as a voltage between +3V and +12V.

The signal takes only TxD, RxD, and Gnd to put together a simple duplex RS-232 communication link. The RS-232 specification says these signals can go about 25 feet (8m) before they become unusable. We can usually send signals a bit farther than this as long as the baud rate is low enough [7].

Chapter 3
System Design

This project is designed into two main parts, hardware and software. The hardware components are the Colpitts oscillator as temperature and humidity measurement instrumentation and microcontroller with minimum system as frequency counter to measure the sensor outputs. On the other hand, the software is used to program the microcontroller as frequency counter with the BASCOM program. To calculate, display, and store data in the PC, the graphic program of LabVIEW is employed. The block diagram of this research is clearly shown in Figure 3.1.

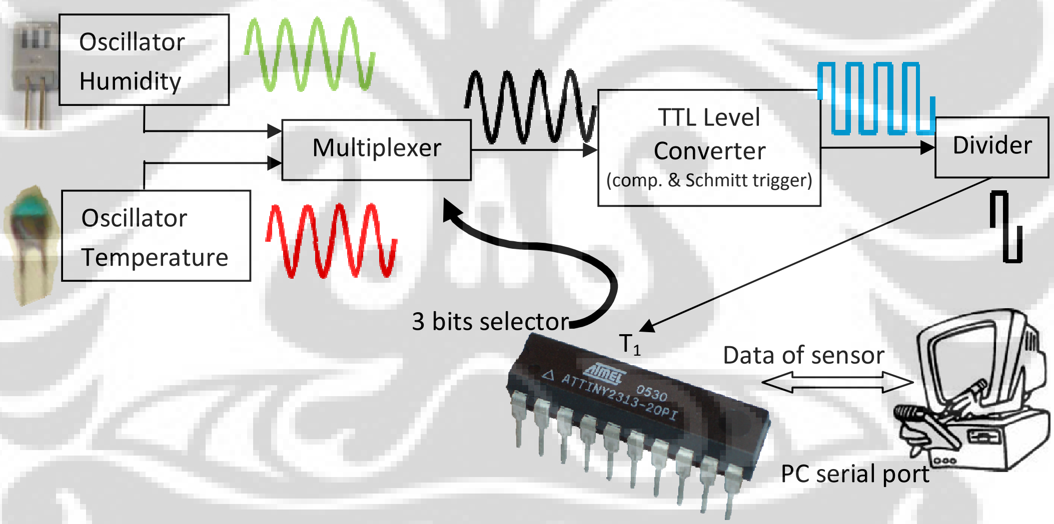


Fig. 3.1 Block diagram of temperature and humidity measurement instrumentation based on Colpitts oscillator

From Fig. 3.1 we can see that to read several inputs from multiple sensors, first the input selector or multiplexer is quite needed to select the data source. We use the oscillator sensors as the source. The analog multiplexer MAX4051 is used here to select which sensor will be processed. The input address in MAX4051 is controlled by microcontroller. A sine wave from the both of sensors should be converted to TTL form before preceded by divider and microcontroller. Finally, the data is proceeded by microcontroller itself so that the final result could be sent to PC serial port as a data of particular node's frequency of temperature or humidity. The PC is not only to show real time data, but also as controller, saver, and converter the frequency value to the real physical value.

3.1 Hardware Design

Hardware components from this project can generally be divided into four parts; Colpitts oscillator, TTL level converter, Schmitt trigger and divider, frequency counter, and serial connection to the PC. The every part is clearly described in detail.

3.1.1 Colpitts Oscillator as Temperature and Humidity Measurement Instrumentation

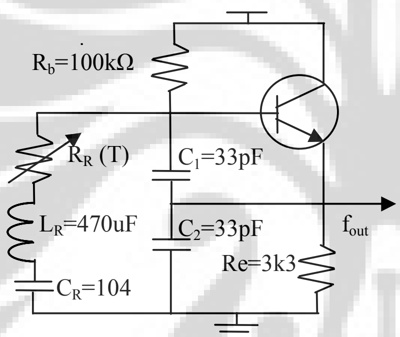


Fig. 3.2 Oscillator Colpitts as temperature sensor

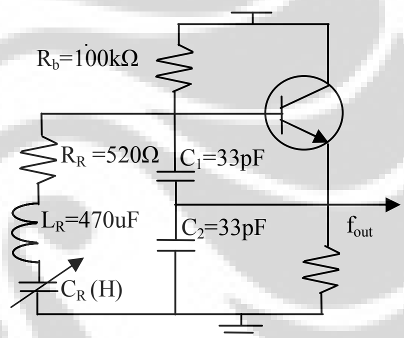


Fig. 3.3 Oscillator Colpitts as humidity sensor

Figure 3.2 and 3.3 describe that one of oscillator components is used as sensor which value changing by the physical phenomenon that will measure. Resistor R_b forward bias the base-emiter junction of transistor when the circuit is initially turned on. The transistor conducts and works at an amplified region and the signals in the system are only the noise voltages generated by the resistor. These noise voltages are amplified by transistor and appear at the output terminals. The amplified noise, which contains all frequencies, drives the resonant feedback circuit. Above and below the resonant frequency, the phase shift is different from 0^0. As a result, oscillations will build up only at the resonant frequency of the feedback circuit matched with circuit component. The amplification of noise is continuing until reach maximum gradually. After stability achieved, the amplifier saturates and brings the oscillator quickly under control and feedback product return 1.

A generating process of sine wave in Colpitts oscillator circuit can clearly be described on Figure 3.4.

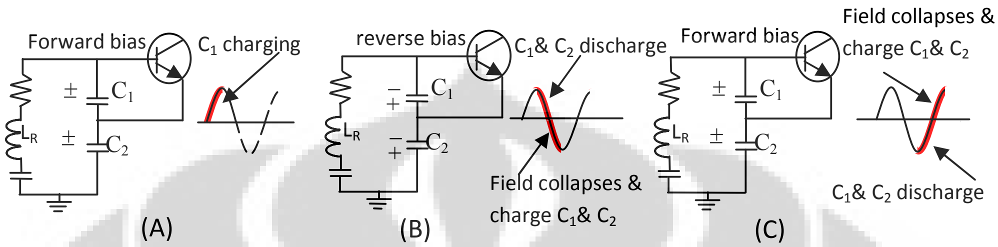


Fig. 3.4 Generating process a sinusoidal in Colpitts oscillator (A) Conducting of transistor and capacitor charging. (B) Transistor on reverse bias. (C) Transistor on forward bias

From Figure 3.4(A) when the circuit is initially energized, the bias circuit establishes base current in transistor. This turn on transistor and collector current is through Vcc to R_E. This charging current through R_E increases voltage V_E positively. The increasing voltage is applied directly to charge C_1 and C_2, producing positive feedback to base transistor. The transistor is further forward bias and quickly *saturates*. When transistor saturated, there is no increase Ic and increasing V_E stops. C_1 and C_2 act as voltage source and current flows from C_1 to C_2. The discharged both of capacitors through L_R build up the magnetic field.

When C_1 and C_2 are completely discharged, the magnetic field collapses and the top C_1 and bottom C_2 negative and positive respectively, reverse biasing of transistor (Figure 3.4(B)). The decreasing Vc makes C_1 negative. This process is continuing until transistor driven into *cutoff*. When feedback capacitor C_1 is fully negative charged, it discharged through L_R. The discharged current flows from C_2 to C_1. The top C_1 and bottom C_2 is positive and negative respectively now. The positive charge of C_1 is applied to transistor so that transistor is now forward biased and conducts (Figure 3.4(C)). A similar action occurs each cycle to create a sinus wave.

3.1.2 TTL Level Converter, Schmitt trigger and Prescaler

The input waveform must be converted from sinusoidal waveform to a square edge pulse waveform in order to operate the logic circuit of the microcontroller. One commonly used technique for converting from sine to square wave is high-speed comparator. Comparator just has two state output either a low or a high voltage vice versa whenever the input voltage is lower or higher than the reference.

LT1016 high-speed comparator from Linear Instrument is employed in this research. The LT1016 is an UltraFast 10 ns comparator that interfaces directly to TTL/CMOS logic while operating off either ±5V or single 5V supplies. Tight offset voltage specifications and high gain allow the LT1016 to be used in precision applications. Matched complementary outputs further extend the versatility of this comparator.

The output from comparator is directly used as input of Schmitt trigger. Schmitt-trigger is extensively used to make the signal smoother and the best solution for the noisy input. The square wave which is derived from Schmitt trigger output is better than if we use comparator only with the same frequency value. The kind of Schmitt trigger ICs employed in this research is 7414.

To be able to measure higher frequencies, prescaler ICs may be used. Finally, the process in signal conditioning is prescaler. A prescaler is defined as an electronic device that takes a frequency and reduces it by a pre-determined factor. For example; converts a 1 MHz signal to a 250 kHz signal (scales the frequency by a factor of 4). Prescaler is generally called divider. If so, the frequency appearing on display should be multiplied by the division ratio to obtain the exact frequency in hertz.

In this research I use TTL dividers 74 LS90 with divide ratios 2, 4, 5, 8 and 10 with 10Mhz maximum frequency input. From all choices I use factor 4, because the frequency output of microcontroller almost 2,5 MHz but the range of frequency counter is just 1 MHz.

3.1.3 Frequency Counter

The design of a frequency meter uses AT-Tiny2313-20PU with 20 MHz crystal to improve the frequency counter ability. A higher crystal clock also expands the range of input signal frequency that can be measured by the frequency counter as well as the minimum pulse of the signal frequency: according to Brüning, the maximum allowable frequency at the counter input pin is a fifth of the processor clock frequency [8].

3.1.4 Connection the Microcontroller to the PC

The simplest port to connect to a PC is the RS232 serial port that communicates with the serial interface. The user needs to set the serial port parameters such as the baudrate (which indicate the bit per second), the number of bits in a transmission, number of stop bits, and the parity bit. The processor can generate most of the standard and popular baud rate with a suitable clock frequency. The distance over RS-232 links can be used –the cable length- is inversely proportional to the baud rate, for baud rates 19200, the cable length can be used up to 10 m.

The serial port of the AVR cannot be connected directly to the PC serial port right away. The RS-232 signals are bipolar and in the range of +12V and -12V, while the AVR can only handle TTL-level signals (if powered by a +5V supply). Also, data as appears on RS-233 line is inverted. That is to say that when the PC wants to send a logic 0, the voltage on the RS-232 line is 12V and when the PC want to send out the logic 1, the line voltage is -12V, so some sort of RS-232 line driver and receiver that converts RS-232 signal levels to TTL, and vice versa, is needed. Also, performing the signal inversion is needed. This problem can override with MAX232 IC. It allows us to convert from TTL level signals from the serial port of microcontroller to serial port of PC. Figure 3.5 illustrates RS-232 link with MAX232 as drivers.

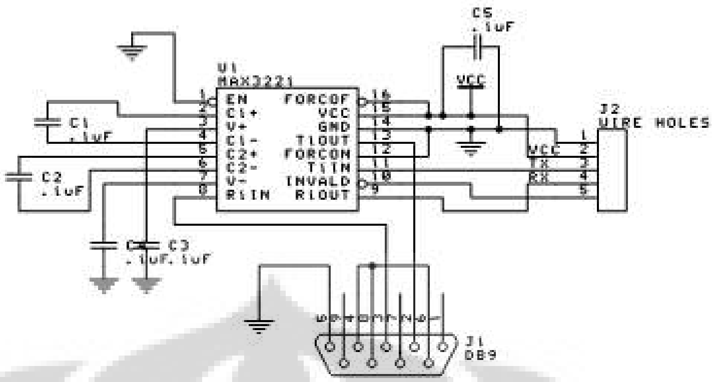


Fig. 3.5 A complete TTL level signals converter to DB9 port

MAX232 from MAXIM Integrated Products has built-in charge-pump power supply circuits to generate the positive and negative signal levels used by the RS-232 system. It, which only requires 5 external capacitors, can transmit and receive at up to 200kbps.

3.2 Software Design

The system works base on computer control to microcontroller for data acquisition and measuring process. The software here consists of two parts, in microcontroller and computer.

3.2.1 Microcontroller Application Program

The program for microcontroller is compiled using the demo version of BASCOM AVR which can be downloaded from website www.mcselec.com. The Colpitts oscillator sensors used as temperature and humidity sensors yield variance of frequency as sensor output. In order to measure frequency the circuit needs a timer to define the gate time as well as a counter to count the number of pulses that arrive during the gate time. However, there is no counter and timer used in this project, just a microcontroller IC.

The solution to this puzzle is that the counters are inside the microcontroller ATtiny2310-20PU. It acts as a counter of incoming frequency from both sensors. There are two internal hardware counters, one is eight bits and the other one is 16 bits. Both of them can be configured as timers or as counters at will. In our application, the 16-bit counter is configured to count the 5 V (TTL- or

CMOS-level) pulses that appear on input of microcontroller. The maximum value that the counter can store is 65535, and this limit is overcome by arranging for an interrupt to occur each time the counter overflows.

The number of interrupts that occurs is counted in the interrupt service routine (ISR). At the end of the gate time the interrupt count is multiplied by 65536 and added to the current counter value. If the gate time is one second, the result will then be the input frequency in Hz:

$$f = (\text{interrupt count} \times 65536) + \text{Timer1 value} \quad (3.1)$$

The gate time is derived from the 8-bit counter, which is configured as a timer with a divide-by-64 prescaler. In this way the 20 MHz processor clock is divided down to create a constant gate time of one second. With the help of mathematics Equation, the frequency converted by the physical value. The flowchart of this program can be seen in Figure 3.6.

Further, we have already developed an algorithm for microcontroller to send the command to control the multiplexer through serial port. As reference, below is the flow of such algorithms:

```
Enable Urxc
On Urxc Rec_isr
Rec_isr:
 Inchar = Inkey()
Select Case Inchar
Case "0" :                                    'temperature selector
   ADDA = 0
   ADDB = 0
   ADDC = 0
Case "1" :                                    'humidity selector
   ADDA = 1
   ADDB = 0
   ADDC = 0
End Select
```

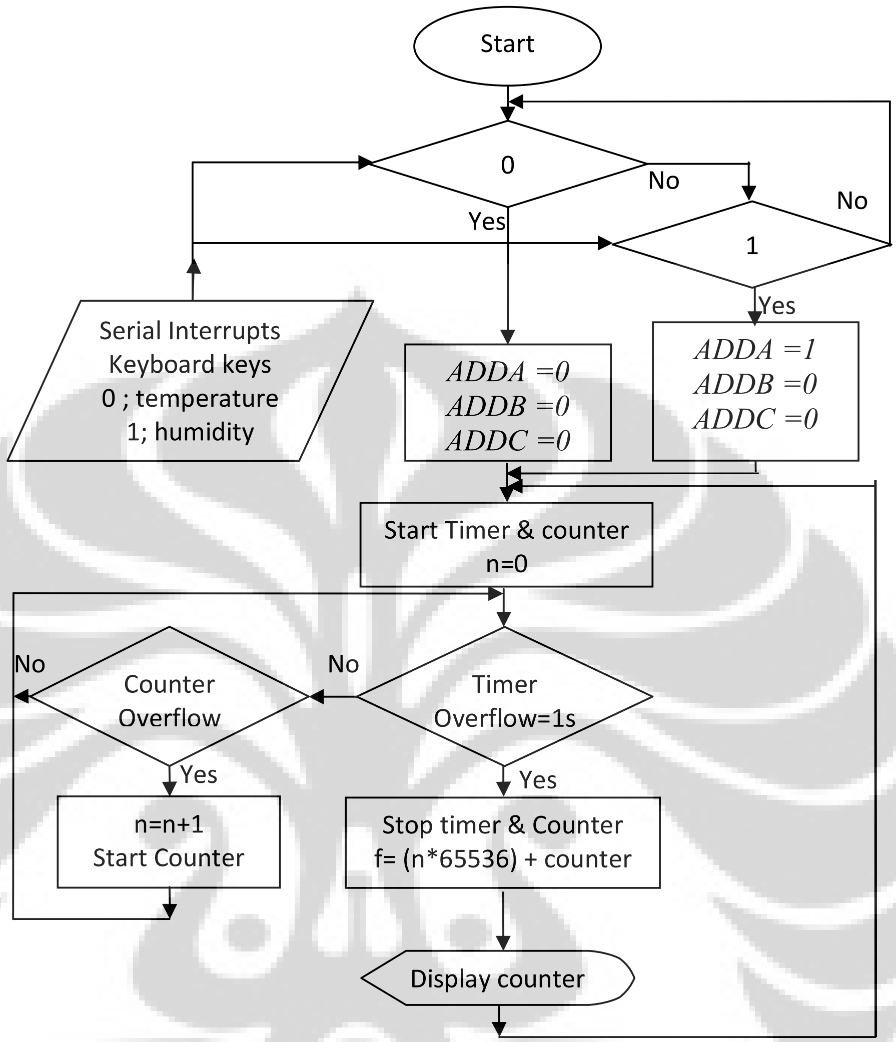


Fig. 3.6. The flowchart of frequency counter

3.2.2 Computer Application Program

The computer program is designed by using LabVIEW which uses a graphical notation in its language. It can create attractive interfaces on the screen and store the acquired data with much less effort. Data acquisition that will be process is gotten from serial port connected to microcontroller.

A computer transfers information (data) one or more bits to start communications, each word (i.e. byte or character) of sent and received data is sent one bit at a time. The serial port is created to receive and transmit data for and from computer to the outside tools. It does with subVI in VISA (Virtual Instrument Software Architecture) palet. VISA is a standard I/O application programming interface for instrumentation programming. VISA can easily control serial instruments and make appropriate driver call depending on the type of instrument being used. We need to set the serial port parameters such as the baud rate (which indicate the bit per second), the number of bits in a transmission, number of stop bits, flow control and the parity. The size of buffer should be set to override the loss data when acquisition process occurred. To decide which sensor and its method of calculation for converting from frequency into physical measurement, VISA Write is used to write "0" and "1" for temperature and for humidity respectively. However, if the changing occur between "0" to "1" or from "1" to "0", the buffer should be cleared by VISA Clear. VISA clear is employed to clear the remaining data in buffer, so the new data will enter to the buffer, and the data which will display, process and save the new incoming data. The name of the file to be saved is based on a day and a date of the first data taken in the first time, this method is used to overcome the file with the same name and to seek the data easily. To close the connection, it is necessary to use the VISA Close if we want to use the port serial to other applications. When the program stops, the LabVIEW will create the average value and create the graph hysteresis base on the average data.

In daily activities, we just need to know the current temperature and humidity data but we don't need to record it. Especially for the comparison purpose between one time to another, we just need to know an average temperature on several time range, e.g. every an hour or even every a day. This condition is very important to minimize a hard disk space for the storage data. By looking this background, On my thesis, the data is displayed every second for both the current and the historical data but for saving purpose, the choice is depend on a user, how far she/he wants to save a data, this choice is can be set by index data. Index data is used to set that how many data will be averaged for saving purpose.

As reference, the flow chart of the LabVIEW program can be seen on the Figure 3.7.

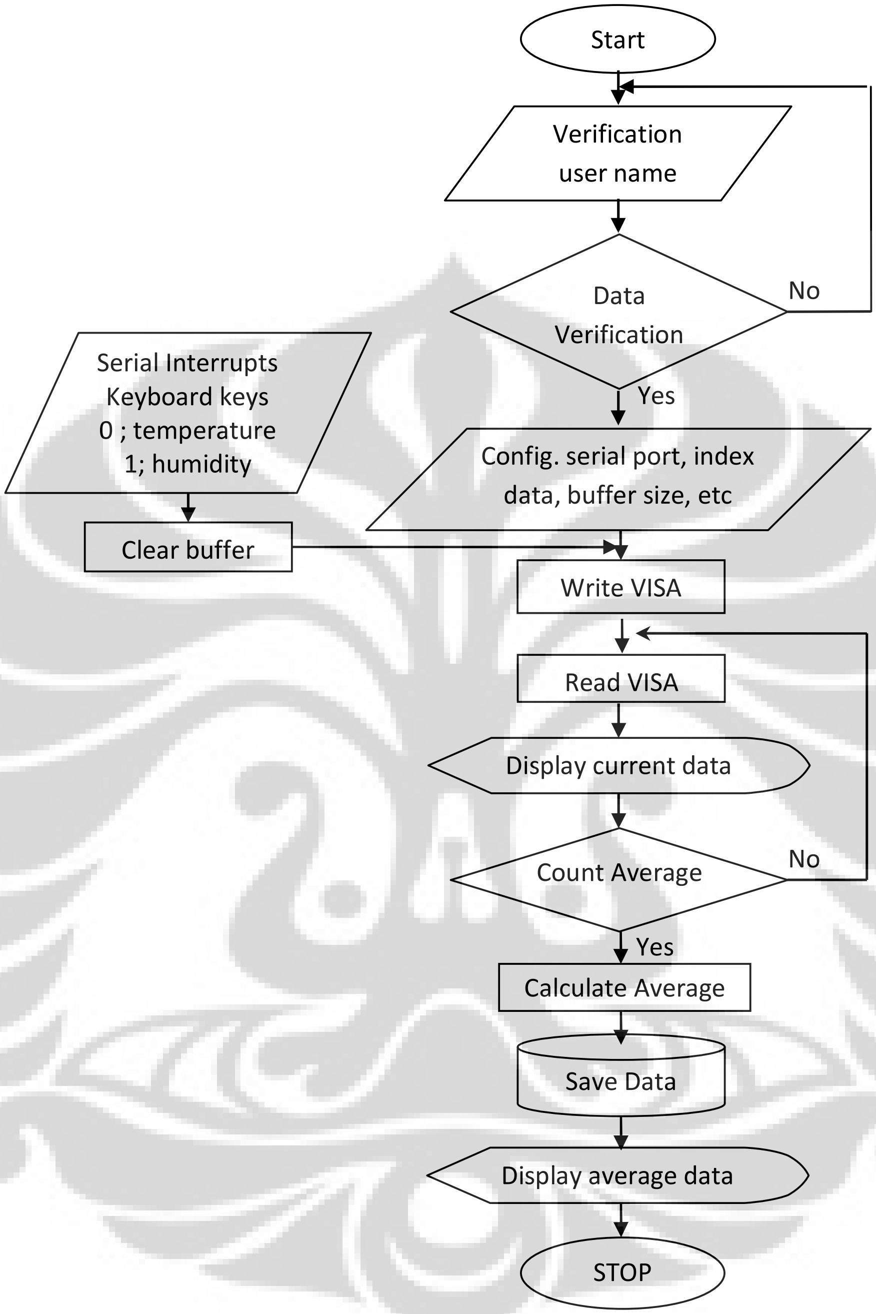


Fig. 3.7 Flowchart of LabVIEW program

Chapter 4

Result and Analysis System

The whole circuits of this project can be instantly divided into 4 parts; sensors, oscillator Colpitts, divider, and frequency counter. In order to guarantee that each part or this project works well, the test of each part has to be done. Therefore all parts are arranged into one system as Temperature and Humidity Measurement Instrument based on Colpitts Oscillator. Urgently, a calibrating process has to be done; so we can create the conclution whether the system can work properly or not.

4.1 Performance Test

4.1.1 Comparison between the Standard Frequency Counter with Frequency Counter

Frequency counter as one of the main parts of this project should be compared with the standard frequency to show the measurement is well done. Generator signal with TTL function is employed as input frequency that is measured with both of instruments. From the 32 data, the compartment gives satisfaction result that can be seen in Figure 4.6. It indicates the proportion of both instruments with correlation coefficient 1 but it is actually not 1. In this case the instrumentation system is able to count up to 1 Mhz before prescaler added, on the other hand, after prescaler added, the instrumentation system can count up until 4 Mhz. If the circuit is arranged in order that PC is able to display up to smallest unit in hertz. It means that the system sensitivity is 10^{-6}.

The resultied graph from comparison between the frequency counter standard versus frequency counter is displayed in Fig. 4.1

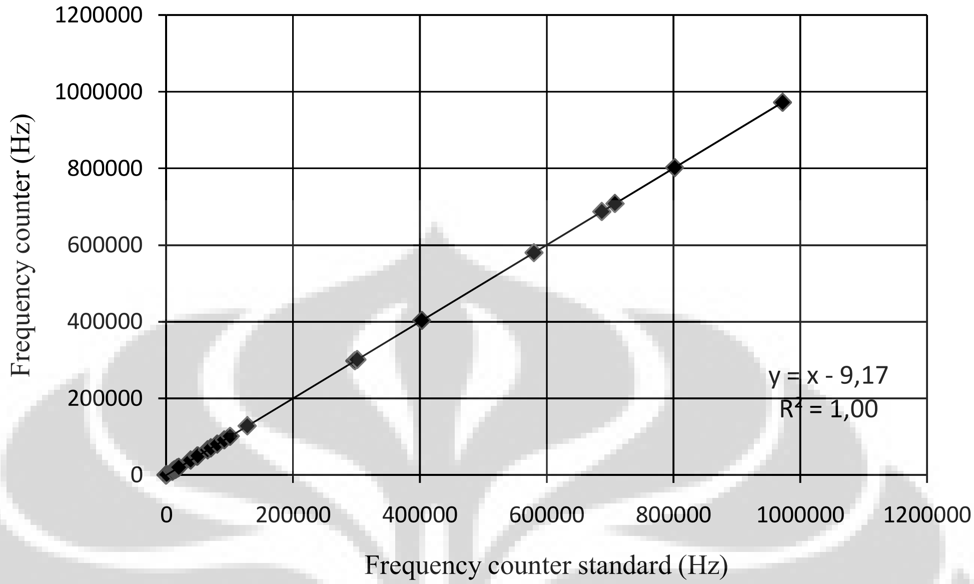


Fig. 4.1 Comparison of the frequency counter standard with frequency counter without prescaler

Figure 4.1 shows that the comparison between the instrumentation and frequency counter display the same result. The offset points with 9,17 can be used as calibrating factor for each measurement.

4.1.2 Relationship between Temperature and Resistance

To guarantee the Thermistors works well, the variance of resistance as temperature function has to be done. The range of temperature chosen to measure is from 0^0C to 100^0C. The special condition that being done is ice temperature and boil water for the 0^0C and 100^0C respectively. A little bit change of resistance of Thermistors as temperature function is easily obtained from increasing temperature with little heater from spirituous lamp, so the small measurable change can be detected. The graph that is resulted from the experimental measurement is represented in Figure 4.2.

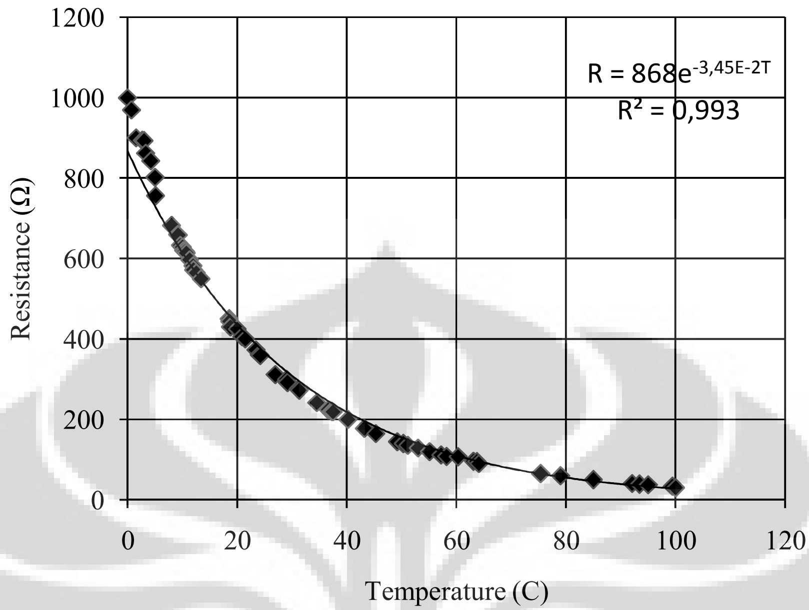


Fig. 4.2 The resistance of Thermistors versus temperature

Figure 4.2 shows the sensor used in this research has electrical resistance that decreases on increased temperature as exponential form and smooth curve is well formed. It matches with typical characters of Thermistors. Little defect on the beginning of the curve occurs not only because of the difficulty of the observation but also the different sensitivity between Thermistors and Thermometer. The change of measurement displays very fast so that I cannot decided which the true value should be recorded.

4.1.3 Relationship between Humidity and Capacitance

According to the datasheet of the sensor used, capacitive humidity sensor is able to measure a relative humidity from 0% to 100% with linear measurement. The relative humidity depends on two factors: the amount of moisture and on the temperature. So we have two modes to change relative humidity; 1. Change the amount of water vapor available, if there is water present, by evaporating the water from that surface will increase humidity. 2. Change the temperature of the air while holding the water vapor constant. Even though there is no water source, and no water vapor is added, a lowering of air temperature results in a rise of relative humidity. This is automatic. The amount of water vapor that could present at saturation decreases on the decreased temperature, so the existing amount of water vapor represents a higher percentage of the saturation level of the air. Similarly, a rise in temperature results in a decrease in relative humidity, even though no water vapor has been taken away.

In order to observe the variance of capacitance and humidity on the constant temperature value, the first method is the best choice of the two. Humidity variance is done by water vapor flowed through a pipe to the closed box 1000 ml to obtain humidity over 60 %. A digital Thermohygro has already used as standard on this project to identify the relative humidity. It can only work from 2 to 99 % of RH with 0 ^{0}C until 50 ^{0}C. The relationship between capacitive value with humidity on temperature range from 30,6 to 31,2 is depicted in Figure 4.3.

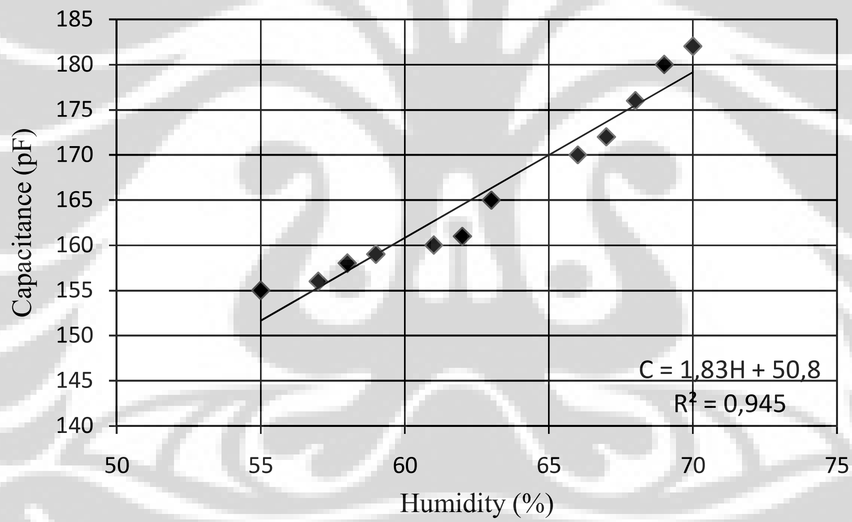


Fig. 4.3 The capacitance of capacitive HS versus humidity

Fig.4.3 clearly shows its electrical capacitance increases on the increased humidity and almost linear function form. Since the temperature on observation box is very difficult to control when the humidity increase, the unlinear graph is the effect on that condition. From that graph, generally we can resume that capacitive humidity censors is able to handle the relative humidity measurement.

4.1.4 The Change of Frequency when Temperature Changes

Correlation study between frequency and temperature is done by using the Thermistors connected to oscillator Colpitts and then the frequency output is directly connected to the frequency counter to identify the oscillation frequency of the circuit. The mercury thermometer has been employed to identify the temperature measured. The change of frequency as of temperature function can be seen in Figure 4.4

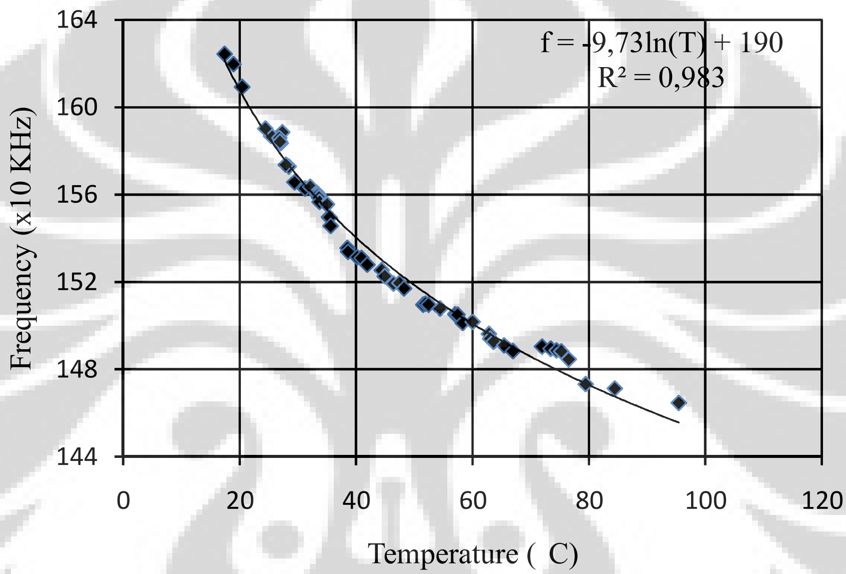


Fig. 4.4 Temperature vs. frequency from 14-92 ^{0}C

Figure 4.4 displays the exponential trend line. Determinative coefficients obtained from research is 0,98 which prove high trust and high correlation between frequency and temperature. By reversing the equation which is also displayed on the graph is used to convert a frequency measurement data to a temperature value by LabVIEW program.

4.1.5 The Change of Frequency when the Humidity Changes

Correlation study between frequency and humidity is done by using humidity sensor (parallel plate capacitor) connected to sensor oscillator and then to frequency counter to identify the oscillated frequency of the circuit. The digital Thermohygro is employed to identify relative humidity. The graph which is resulted by relative humidity versus frequency can be seen in Figure 4.5 that indicates linear relationship with negative slope.

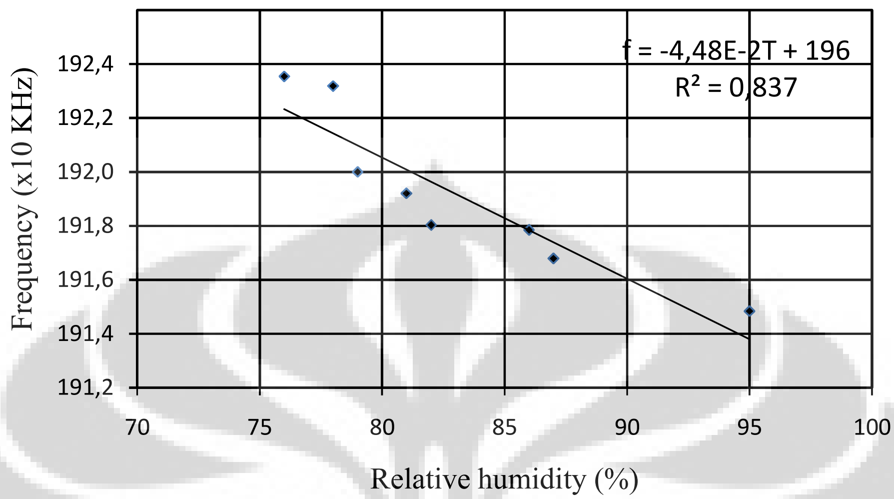


Fig. 4.5 The relationship between relative humidity and frequency

Figure 4.5 shows that the spreads of data are random and/or overlap from one data to others although the determination coefficient shows high trust. It is caused by difficulty of controlling box temperature when observation occurs. On the other hand, the fluctuation of frequency output also influences the recorded data. The Equation which is obtained from frequency versus humidity is very important to be employed on data analysis in LabVIEW.

4.1.6 Divider

To be able measuring higher frequency than frequency counter ability, divider IC 74LS90 with 4 dividing ratios is used here. The schematic of that process is figure out in Figure 4.6

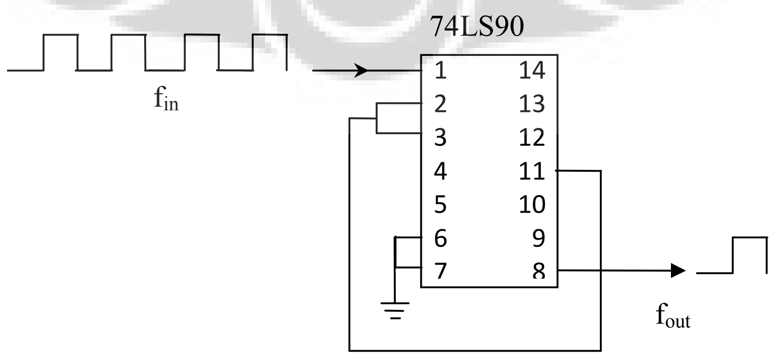


Fig.4.6. Divided by 4 from 74LS90

In order to guarantee the prescaler work properly, the frequency input is taken from TTL generator function. With 100 and 400 Hz input, the output values which is detected are 25 and 100 Hz respectively. From the measurement test, the divider is guaranteed to work well.

4.1.7 Comparison between Calculated and Practical Frequency Colpitts Oscillator

The comparison between the calculated frequency derived from Chapter 2 and measured result is plotted on Figure 4.7 and Figure 4.8 for resistance of Thermistors and capacitance of capacitive humidity sensor respectively.

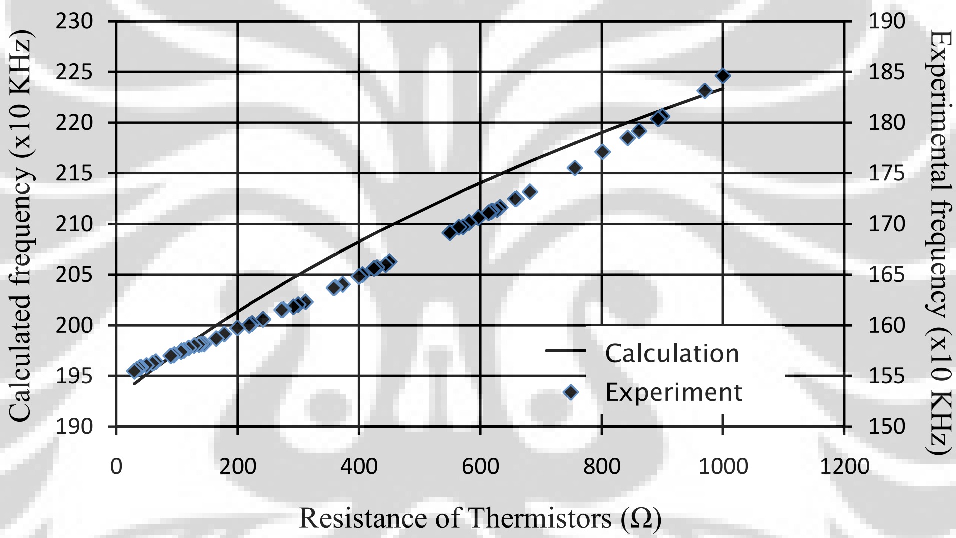


Figure 4.7 Frequencies of theoretical and practical Colpitts versus resistance of resistive resonator

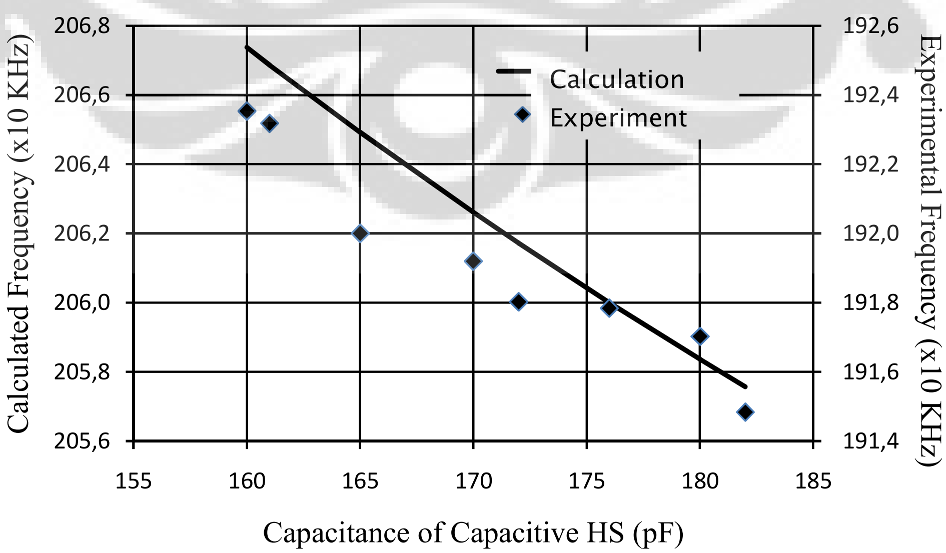


Figure 4.8 Frequencies of theoretical and practical Colpitts versus capacitance of capacitive resonator

By using R_0 = 500 Ω on the Equation 2.14, the range of frequency output between the theory and practice shows a close value. Generally, trend line between theory and practice also show the same pattern. The frequency of resistance variance increases with resistance increase, but the frequency of capacitance variance decreases with capacitance increase.

4.1.8 Comparison between Instrumentation and Instrumentation Standard

The comparison between the temperature derived from Thermometer standard and temperature instrumentation that has been created is plotted on Figure 4.9 (data in appendix on Table 14, while, the Hygrometer standard in horizontal axis and hygrometer instrumentation in vertical axis are displayed in Figure 4.10. The standard deviations of thermometer and hygrometer instrumentation are 1,5 and 3,9 respectively, so results of instrumentation are (T±1,5) ^{0}C for Thermometer and (H±3,9) % for Hygrometer.

Figure 4.9 shows that the data from instrumentation and Thermometer standard is almost close. It can be seen from the cost variable 0,975 and determination coefficient 0,993. The same manner also occurs with Hygrometer. The cost variable and determination coefficient are 1 and 0,752.

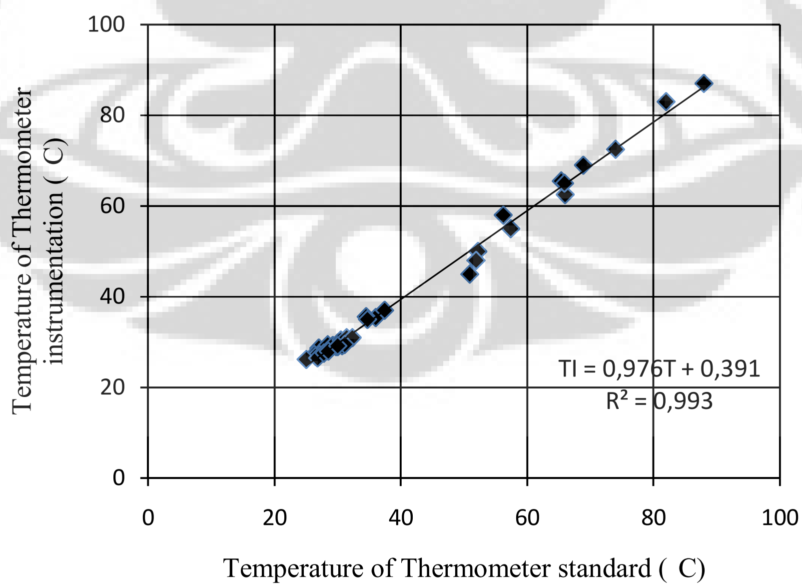


Fig. 4.9. Thermometer standard versus Thermometer instrumentation

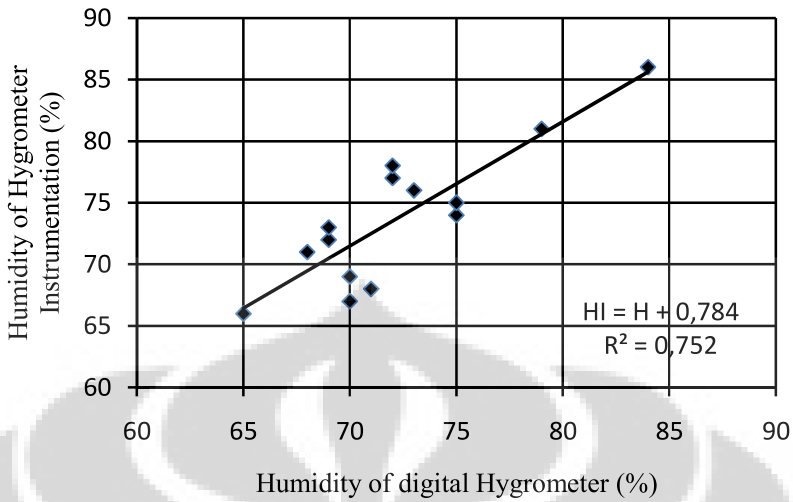


Fig. 4.10 Hygrometer standard versus Hygrometer Instrumentation

4.1.9 Error bar

Error bars express potential error amounts that are graphically relative to each data point, while data points are individual values plotted in a chart and represented by bars, columns, lines, pie or doughnut slices, dots, and various other shapes called data markers [13].

The error bars of temperature and humidity measurement instrumentation are shown in Figure 4.11 and 4.12. Figure 4.11 shows the each data from Thermometer instrumentation at any range of temperature does not overlap, so the each data is distinguishable from one another. It is very difference with Figure 4.12 which is overlap from 68 to 74 % and the data very difficult to distinguish.

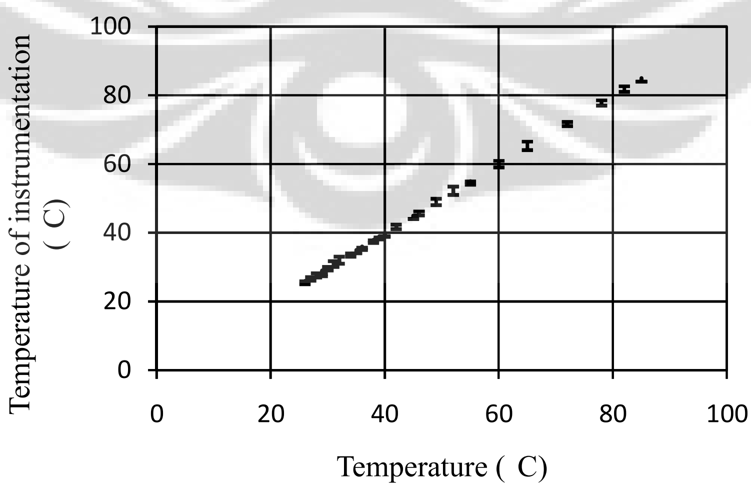


Figure 4.11 The error bars of Thermometer instrumentation

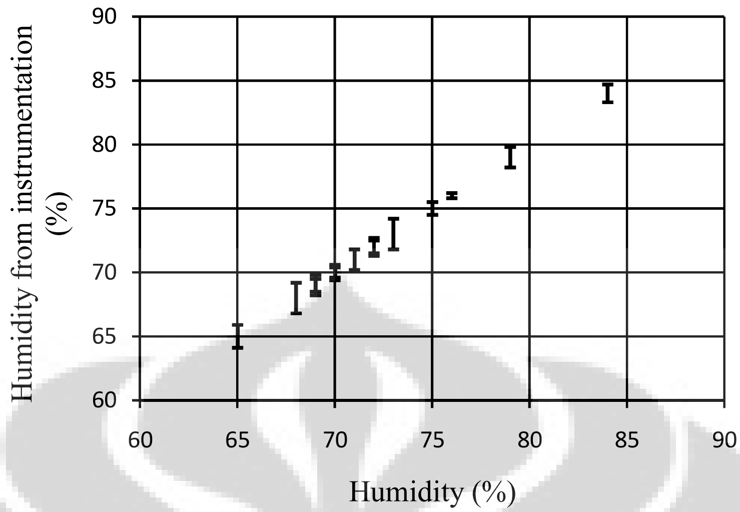


Figure 4.12 The error bars of Hygrometer instrumentation

4.2 Computer Display

The controlling, displaying and saving software are created by graphical programming LabVIEW which consists of several main parts. Several of them are login identification, serial configuration, electing sensor, current and average data on graph and table display. The Equation gotten from Figure 4.3 and 4.4 are used to convert the frequency measurement to physical parameter temperature and humidity. Figure 4.10, 4.11, 4.12, 4.13 show temperature screen, humidity screen, data table and graph of temperature average as along as measuring occurrence.

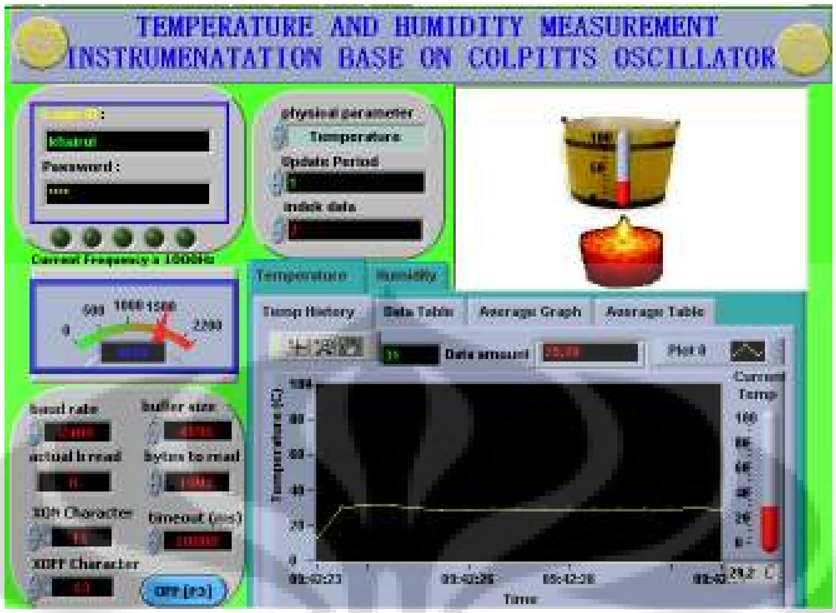


Figure 4.13. Computer screen of temperature measurement instrumentation

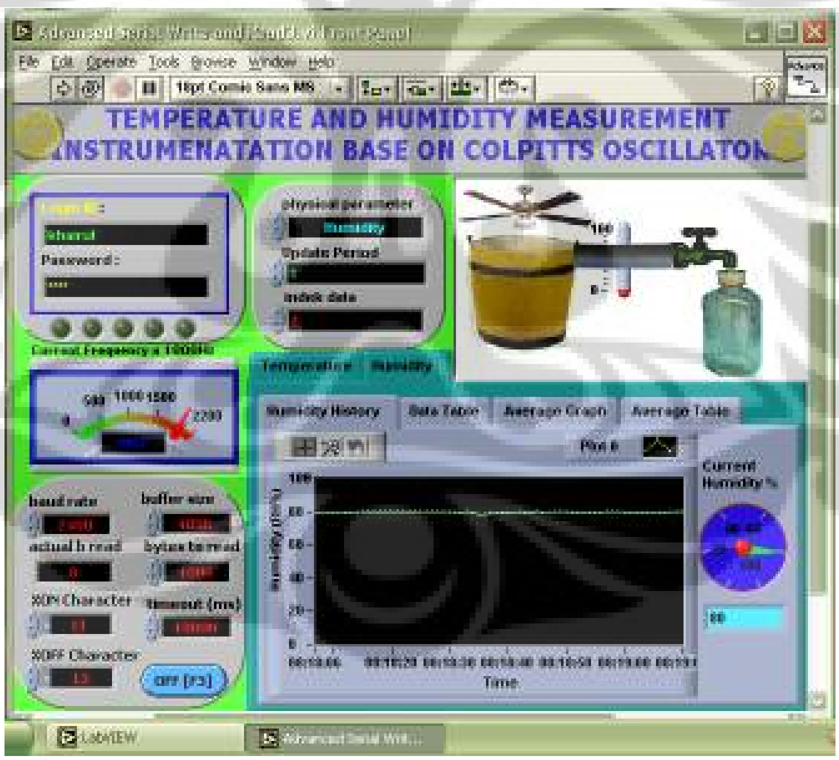
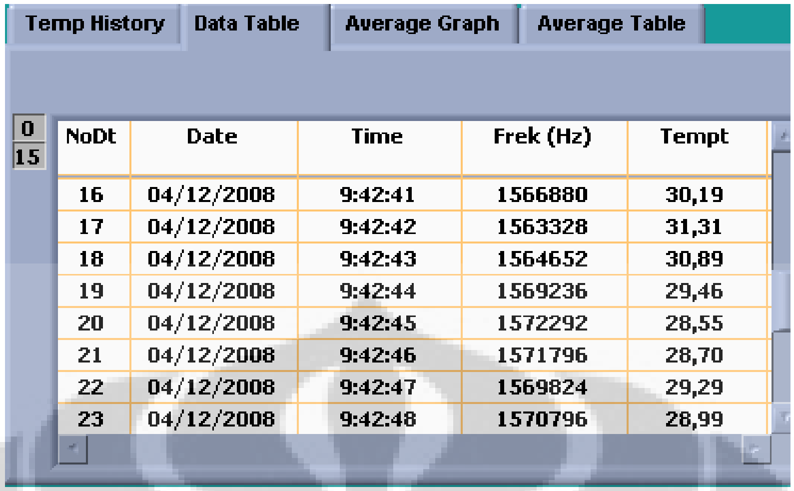


Figure 4.14. Computer screen of humidity measurement instrumentation



NoDt	Date	Time	Frek (Hz)	Tempt
16	04/12/2008	9:42:41	1566880	30,19
17	04/12/2008	9:42:42	1563328	31,31
18	04/12/2008	9:42:43	1564652	30,89
19	04/12/2008	9:42:44	1569236	29,46
20	04/12/2008	9:42:45	1572292	28,55
21	04/12/2008	9:42:46	1571796	28,70
22	04/12/2008	9:42:47	1569824	29,29
23	04/12/2008	9:42:48	1570796	28,99

Figure 4.15. Temperature data on table form

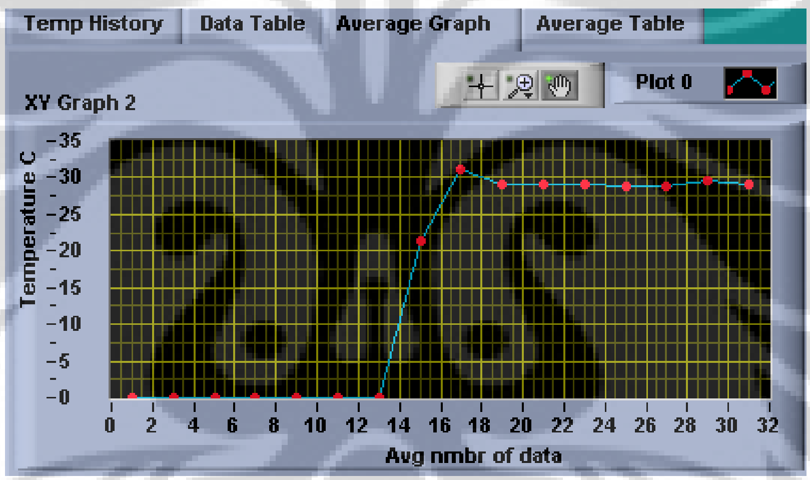


Figure 4.16. Temperature data average on chart

4.3 Analysis

4.3.1 Hardware and Software

From the measurement test that have been done as long as the data acquisition for researching purposes, hardware and software have been integrated and they work properly for temperature and humidity measurement. The Colpitts oscillators can well detect temperature and humidity. On the other hand, the frequency output resulted from experiment and theory is almost matching that explains the perfect hardware design. Microcontroller system built is able to measure frequency up to 1 MHz and up to 4 MHz if prescaler added. The last, the computer software can well handle the all part into an integrated system for controlling, saving, and displaying data.

4.3.2 Sensitivity

The sensitivity is defined in terms of the relationship between input physical signal and output electrical signal or the slope of the calibration curve [7]. It is generally the ratio between a small change in electrical signal and a small change in physical signal. As such, it may be expressed as the derivative of the transfer function with respect to physical signal.

From the Equations displaying in Fig. 4.2 and 4.3, the sensitivity sensors are (29,9 $\exp^{-3,45E-2T}$) $\Omega/^0C$ and 1,83 x 10^{-9} F/%RH for temperature and relative humidity respectively. On the other hand, the sensitivity of Colpitts oscillator are = (-9,74E4/T) Hz/^{0}C for temperature and -4,48E3 Hz/%RH for humidity. Based on that condition, we can resume that, Colpitts oscillator are significantly able to improve the sensitivity of sensors.

4.3.3 Resolution

Resolution is defined as the input increment that gives some small but definite numerical change in the output or the smallest measurable input *change* [7]. The smallest change of temperature can be detected is 0,1 ^{0}C while the humidity is 1%. When temperature is 33,2, the frequency output of oscillator sensor is 1560800, while temperature is 33,3 the frequency output is 156000. On the other hand, when the humidity is 70 and 71 % at 30,4 ^{0}C, the frequency output is 1792268 and 1791728 respectively. From those condition, the instrumentation can have resolution 0,1 ^{0}C for temperature and 1 % for humidity.

Chapter 5

Conclusion and Suggestion

5.1 Conclusion

This project describes the design of a simple oscillator as temperature and humidity measurement instrumentation, which employs variable resonator detecting both of physical parameters. The designed process began with oscillator Colpitts with variable resonator, followed by addition frequency counter to count the frequency output of the oscillator. Finally, the LabVIEW is employed to display, calculate and save data at the end of this process. From that condition, we can conclude:

1. This project has been successfully created the temperature and humidity measurement instrumentation based on Colpitts oscillator.
2. Correlation between both temperature (T), and humidity (RH) with frequency (f) are displayed with the following equations;

   $T = 2,29\ 10^{8} \exp(-1,01\ 10^{-5} f)$

   $RH = -1,87\ 10^{-3} f + 3,6\ 10^{3}$ at 28 ^{0}C.
3. Converted sensor output to frequency is one of the ways to improve sensitivity of the sensor. The sensitivity of temperature and humidity after include on Colpitts oscillator are $((-9,73\ 10^{4})/T)$ Hz/^{0}C and $-4,48\ 10^{2}$ Hz/%RH respectively. On the other hand, the sensitivity of both sensors originally are $(29,9\ \exp^{-3,45E-2T})$ $\Omega/^{0}$C and $1,833 \times 10^{-9}$ F/%RH for temperature and humidity respectively.
4. The resolutions of instrumentation are 0,1 ^{0}C and 1 % for temperature and humidity respectively.
5. AT-tiny 2313-20PU is successfully able to measure a frequency up to 1 MHz without prescaler.
6. LabVIEW can well handle all processes like serial communication, manipulation, store and display data with real time.

5.2 Suggestion

To improve and repair this research in the future, there are several points which should be considered for other designers:

1. When designing the project which correlates with frequency, the component characteristic must be clearly observed on maximum frequency responds especially.
2. Capacitive RH sensors can only measure the amount of water which is flown upon the sensor, so we must calibrate it at any temperature range and employs microprocessor-based circuit or LabVIEW to store calibration data.
3. From the three oscillator components, only the inductor has not been used yet. In the future research, the sensors that are principle inductor alike may be used.
4. The resistive Thermistors employed in the resonator (positive resistance) must be less than the negative resistance. In practice, a positive resistance must be less than a fifth negative resistance. If that condition forces occurrence, the frequency output cannot be resulted.
5. Colpitts oscillator stability is very influenced with temperature, electric field, magnetic field and mechanical disturbance. Overriding of those trouble should be thought on the future.

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B. APPENDIX

Data Tables

Table 1. Resistance of Thermistors on temperature variance

No	Temperature (^0C)	R(ohm)	No	Temperature (^0C)	R(ohm)
1	0	1000	31	24,2	359
2	0,7	970	32	26,9	312
3	1,5	900	33	29	300
4	2,7	894	34	29,2	292
5	3	893	35	31,1	276
6	3,3	862	36	31,3	273
7	4,2	843	37	34,5	242
8	5	802	38	36,6	224
9	5,1	756	39	37,2	220
10	8	682	40	37,5	219
11	9,1	660	41	40,2	200
12	9,2	658	42	43,2	178
13	9,6	633	43	45,3	165
14	10	628	44	49,2	145
15	10,2	620	45	50,3	140
16	10,5	618	46	51,1	136
17	10,7	614	47	53	129
18	11,3	597	48	55,1	120
19	11,9	582	49	57,2	112
20	12	572	50	58,2	108
21	12,5	565	51	60,3	107
22	13,4	550	52	63,1	96
23	18,5	450	53	63,7	95
24	18,6	444	54	64,1	90
25	18,8	430	55	75,4	65
26	20	425	56	79	60
27	20,9	406	57	85	50
28	21,5	400	58	92,1	41
29	23,4	373	59	93,4	39
30	24	361	60	95	38
31	24,2	359	61	99,4	34
			62	100	30

Table 2. Capacitance of capacitive humidity sensor on humidity variance in 30-31 ^{0}C

No	Humidity	Capacitance (pF)	Temperature (^{0}C)
1	55	155	31,1
2	57	156	31,2
3	58	158	30,9
4	59	159	30,6
5	61	160	30,8
6	62	161	30,7
7	63	165	30,8
8	66	170	30,7
9	67	172	31
10	68	176	30,8
11	69	180	30,8
12	70	182	30,8

Table 3. Frequency output of Colpitts oscillator with temperature variance

No.	Frequency (Hz)	Tempm (^{0}C)
1	1562720	31,2
2	1563520	32,1
3	1565620	29,4
4	1572824	28,4
5	1573600	27,9
6	1584200	26,8
7	1583500	27
8	1588500	27,3
9	1586768	25,4
10	1585844	26,8
11	1590180	24,4
12	1584184	26,9
13	1624280	17,4
14	1619620	18,9
15	1609240	20,4
16	1560800	33,2
17	1560000	33,3
18	1559880	33,5
19	1558668	33,6
20	1556604	33,7
21	1555724	34,9
22	1555492	35
23	1549620	35,3
24	1549576	35,4
25	1545600	35,6
26	1535480	38,5
29	1530920	40,9
30	1527864	41,9
31	1525400	44,4
32	1522600	44,9
33	1519240	46,4
34	1519520	47,4
35	1517040	48,2
36	1509536	51,5
37	1510000	51,9
38	1509600	52,4
39	1507820	54,4
40	1505200	57
41	1505044	57,4
42	1501200	58,3
43	1501708	60
44	1496232	62,8
45	1494000	63
46	1492648	63,6
47	1490984	65,4
48	1488328	66,9
49	1490400	71,9
50	1489440	73,4
51	1488632	74,4
52	1488232	75,2
53	1484544	76,5
54	1473200	79,4
55	1471200	84,4

27	1533784	38,6	56	1464600	95,4

Table 4. Frequency output of Colpitts oscillator with humidity variance in 27 ^{0}C

No.	Frequency (Hz)	Humidity (%)
1	1927536	76
2	1923300	85
3	1920964	86
4	1919204	87
5	1916788	88
6	1912520	90
7	1918024	82
8	1926600	95

Table 5. Frequency output of Colpitts oscillator with humidity variance in 28 ^{0}C

No.	Frequency (Hz)	Humidity (%)
1	1923536	76
2	1923180	78
3	1920000	79
4	1919200	81
5	1918024	82
6	1917846	86
7	1916788	87
8	1914836	95

Table 6. Frequency output of Colpitts oscillator with humidity variance in 28,7 ^{0}C

No.	Frequency (Hz)	Humidity (%)
1	1913836	95
2	1916900	77
3	1919940	75
4	1914640	78
5	1914048	81

Table 7. Frequency output of Colpitts oscillator with humidity variance in 30 ^{0}C

No.	Frequency (Hz)	Humidity (%)
1	1916664	74
2	1910324	73
3	1907854	72
4	1910000	71
5	1913000	69
6	1911280	70
7	1911800	71
8	1911380	72

Table 8. Frequency output of Colpitts oscillator with humidity variance in 30,5 ^{0}C

No.	Frequency (Hz)	Humidity (%)
1	1792268	70
2	1791728	71
3	1791000	73
4	1790984	75
5	1790868	77
6	1790684	78
7	1790632	79
8	1786520	80
9	1780760	95

Table 9. Frequency measurement on frequency meter standard and instrumentation

No.	F stand. (Hz)	F inst. (Hz)	No.	F stand. (Hz)	F inst. (Hz)
1	30	30	17	48900	48986
2	49	49	18	50080	50100
3	100	100	19	65400	65470
4	125	125	20	70.650	70680
5	480	480	21	80780	80751
6	1000	1000	22	92000	91902
7	10100	10103	23	101000	101088
8	12650	12701	24	128000	128127
9	14560	14578	25	297600	297652
10	15027	15027	26	301200	301179
11	16872	16875	27	403200	403112
12	17723	17710	28	580000	579374
13	18010	18010	29	687000	687050
14	19000	19000	30	707800	707933
15	20076	20100	31	801900	802001
16	38700	38754	32	972000	972142

Table 10. Practical and theoretical frequency of oscillator Colpitts as temperature measurement instrumentation

No.	R:varied	f Practice	F Theory	No.	R:varied	f Practice	F Theory
1	2	3	4	5	6	7	8
1	1000	1846000	2,23E+06	32	756	1755200	2,18E+06
2	970	1831240	2,23E+06	33	682	1731640	2,16E+06
3	900	1806132	2,21E+06	34	660	1724892	2,16E+06
4	894	1803972	2,21E+06	35	658	1724400	2,16E+06
5	893	1803572	2,21E+06	36	633	1716040	2,15E+06
6	862	1791660	2,20E+06	37	628	1714200	2,15E+06
7	843	1784800	2,20E+06	38	620	1712800	2,15E+06
8	802	1771244	2,19E+06	39	618	1712056	2,15E+06

9	614	1710640	2,14E+06	40	219	1600000	2,02E+06
10	597	1706000	2,14E+06	41	200	1597240	2,01E+06
11	582	1701332	2,14E+06	42	178	1591200	2,00E+06
12	572	1697200	2,13E+06	43	165	1586680	2,00E+06
13	565	1696800	2,13E+06	44	145	1581600	1,99E+06
14	550	1691252	2,13E+06	45	140	1581400	1,99E+06
15	450	1662560	2,10E+06	46	136	1580880	1,99E+06
16	444	1659800	2,10E+06	47	129	1580000	1,99E+06
17	430	1657000	2,09E+06	48	120	1577600	1,98E+06
18	425	1656000	2,09E+06	49	112	1575200	1,98E+06
19	406	1649800	2,08E+06	50	108	1574800	1,98E+06
20	400	1648200	2,08E+06	51	107	1573600	1,98E+06
21	373	1640400	2,07E+06	52	96	1570964	1,97E+06
22	361	1637720	2,07E+06	53	95	1570564	1,97E+06
23	359	1636800	2,07E+06	54	90	1570000	1,97E+06
24	312	1622960	2,05E+06	55	65	1564000	1,96E+06
25	300	1620400	2,05E+06	56	60	1562400	1,96E+06
26	292	1618000	2,05E+06	57	50	1560400	1,95E+06
27	276	1615604	2,04E+06	58	41	1558480	1,95E+06
28	273	1615000	2,04E+06	59	39	1558000	1,95E+06
29	242	1605884	2,03E+06	60	38	1557760	1,95E+06
30	224	1601720	2,02E+06	61	34	1556600	1,94E+06
31	220	1600460	2,02E+06	62	30	1554720	1,94E+06

where :

C_1= 29 pF C_2= 29 pF C_R= 10000 pF L_R=4,7 10^{-4}H R_0=500Ω

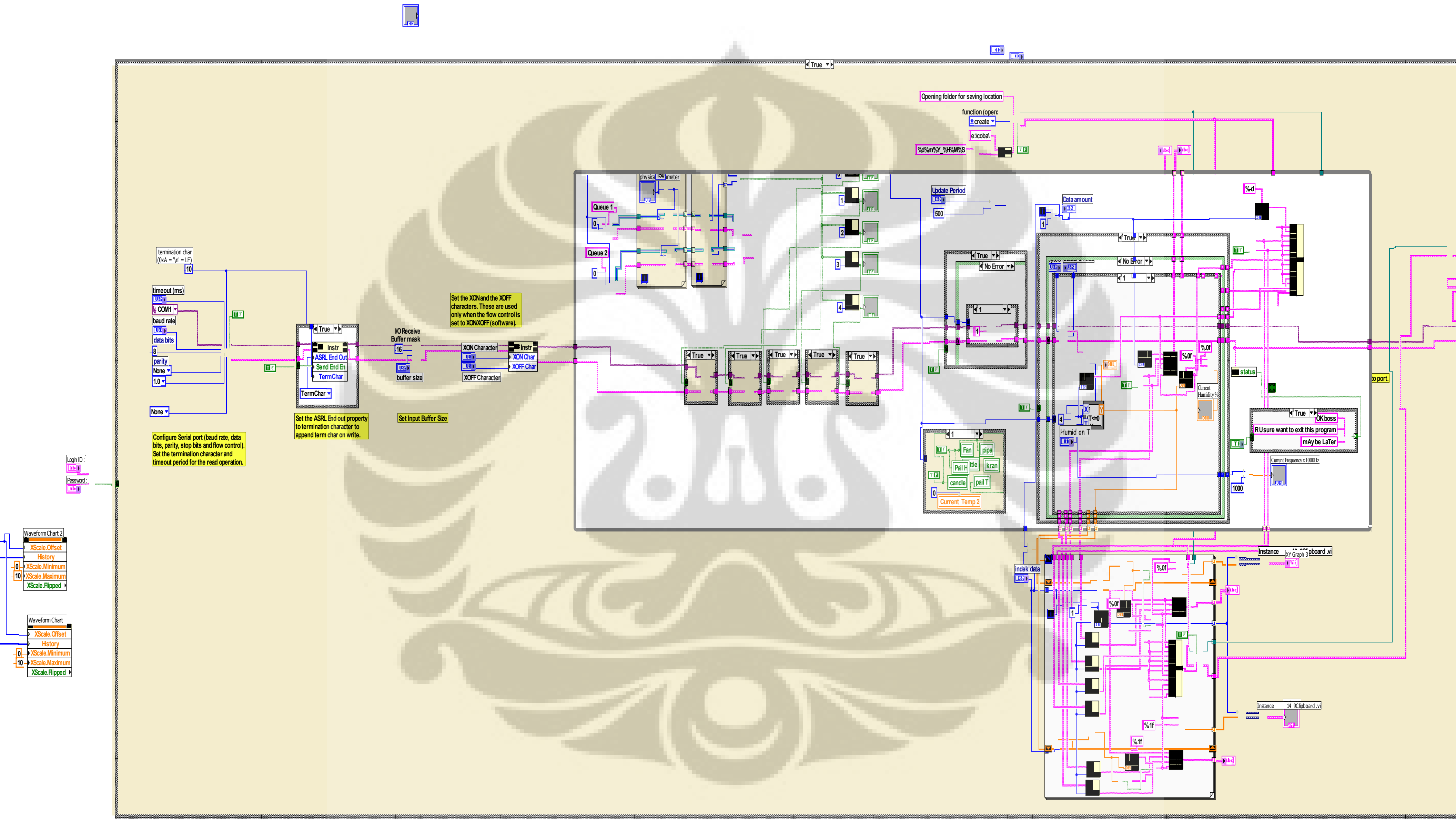
Table 11. Practical and theoretical frequency of oscillator Colpitts as humidity measurement instrumentation

No	C varied (pF)	F practice (Hz)	F Theory (Hz)
1	160	1923536	2067374
2	161	1923180	2066871
3	165	1920000	2064920
4	170	1919200	2062608
5	172	1918024	2061720
6	176	1917846	2060004
7	180	1917024	2058363
8	182	1914836	2057569

Where C_1= 29 pF C_2= 29 pF R_R= 520 Ω L_R=4,7 10^{-4}H R_0=500Ω

Table 12. Temperature measurement on thermometer standard and instrumentation

No.	Instrumentation (^{0}C)	Standard (^{0}C)	Δx (^{0}C)	Δx^2
1	28,2	28,3	-0,1	0,01
2	28,1	28	0,1	0,01
3	28,8	28,6	0,2	0,04
4	27	28,7	-1,7	2,89
5	29	28,9	0,1	0,01
6	29,7	29	0,7	0,49
7	30	29	1	1
8	28,6	28,6	0	0
9	26,3	27,3	-1	1
10	27,1	27,5	-0,4	0,16
11	27,3	27,5	-0,2	0,04
12	26,5	26,9	-0,4	0,16
13	25	26,2	-1,2	1,44
14	26,8	26,5	0,3	0,09
15	28,4	29,4	-1	1
16	27,8	27,6	0,2	0,04
17	30,1	29,2	0,9	0,81
18	30,7	29,3	1,4	1,96
19	29,2	29,3	-0,1	0,01
20	30,1	29,2	0,9	0,81
21	30,7	29,2	1,5	2,25
22	27,8	27,6	0,2	0,04
23	28,5	28	0,5	0,25
24	36	35,4	0,6	0,36
25	34,5	35,6	-1,1	1,21


termination char (0xA = '\n' = LF)
timeout (ms)
COM1
baud rate
data bits
parity
None
1.0
None
Configure Serial port (baud rate, data bits, parity, stop bits and flow control). Set the termination character and timeout period for the read operation.
Set the ASRL End out property to termination character to append term char on write.
I/O Receive Buffer mask
buffer size
Set Input Buffer Size
Set the XON and the XOFF characters. These are used only when the flow control is set to XONXOFF (software).
XON Character
XOFF Character
Queue 1
Queue 2
Opening folder for saving location
function (open:
create
Update Period
500
Data amount
Humid on T
Current Temp 2
status
OK boss
RUsure want to exit this program
mAybe LaTer
to port.
indek data
Login ID :
Password :
Waveform Chart 2
Waveform Chart
XScale.Offset
History
XScale.Minimum
XScale.Maximum
XScale.Flipped