DESIGN OF AN AUTOMATIC ANTENNA TUNER

SITI AFIFAH BINTI HASSAN

Thesis submitted fulfillment of the requirements

for the award of the degree of

Bachelor of Engineering in Mechatronic

Faculty of Manufacturing Engineering

UNIVERSITI MALAYSIA PAHANG

SEPT 2013

ABSTRACT

This thesis presents the design of an Automatic Antenna Tuner. Automatic Antenna Tuner is used to improve the power transfer on the transmission line by matching the impedance of the tuner to antenna. It attempts to convert the input impedance to 50Ω to matching with the antenna impedance. It is also used to control the switching components to load the signal frequency. The objectives of this project are to develop the software system to control the switching components, to develop an LC circuit and to find the best combination of inductor and capacitor to load the signal frequency. This thesis describes the development of the automatic antenna tuner and the criteria needed to develop the equipment. The range of frequency, that the automatic antenna tuner able to load is 3-23MHz.

ABSTRAK

Tesis ini membentangkan reka bentuk *Automatic Antenna Tuner*. *Automatic Antenna Tuner* digunakan untuk meningkatkan pemindahan kuasa pada talian penghantaran dengan memadankan impedans penala dengan antenna. Ia bertindak menukar impedans yang masuk kepada 50Ω untuk menyepadankan dengan impedans antenna. Ia juga digunakan untuk mengawal suis komponen bagi mendapatkan isyarat kekerapan. Objektif projek ini adalah untuk membangunkan sistem perisian untuk mengawal suis komponen, untuk membangunkan litar LC dan untuk mencari kombinasi terbaik induktor dan kapasitor untuk mendapatkan isyarat kekerapan. Tesis ini menerangkan pembangunan penala *Automatic Antenna Tuner* dan kriteria yang diperlukan untuk membangunkan penala tersebut. Rangkaian kekerapan yang penala ini dapat hasilkan adalah 3-23MHz.

TABLE OF CONTENT

CHAPTER 2 THEORETICAL REVIEW OF PROJECT

CHAPTER 3 FLOW WORK AND METHOD OF THE PROJECT

LIST OF TABLES

LIST OF THE FIGURES

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The purpose of this chapter is to give brief explanation about the introduction of this project. All general information of the project was discussed in this chapter. This chapter includes background of project, problem statement, objectives, scope of project and project expectation.

1.2 PROJECT BACKGROUND

Antenna is an electrical device that converts electrical power into radio waves. Usually, it is used together with the radio transmitter. An antenna tuner is a device that connected between radio transmitter and antenna. The purpose of antenna tuner is to improve power transfer on the transmission line by matching the impedance of the equipment to antenna.

In practical terms, all tuner does is act as a kind of adjustable impedance transformer between the antenna system and the radio. It takes any value of impedance the antenna system presents and attempts to convert it to 50 Ω or some reasonable impedance for the transceiver. When the input impedance is 50 Ω, it is able to load its maximum RF output into the system. The power is transferred through the antenna tuner, to the feed line and to the antenna. Radio transmitter supplies oscillating radio frequency electric current to the antenna terminal. The antenna will radiates energy from the current as electromagnetic wave. Antenna intercepts some of the power of the electromagnetic wave to produce tiny voltage at its terminal which is applied to the receiver to be amplified. The ideal standing wave ratio for perfect impedance matching on transmission line is 1.

1.3 PROBLEM STATEMENT

Antenna tuner become most of the important equipment in this world because it is very useful to make sure that radio and television to get the signal. Most of the antenna tuner was built to operate manually. When connected to different radio and antenna, the antenna does not matched properly. The tuner must be adjusted manually to match the impedance of the antenna and this step will take a lot of time as the tuner must be adjusted properly to make sure that the antenna has been match properly and to get a good signal.

1.4 OBJECTIVES

The objectives of this project are:

1. To develop software system to control the matching component.
2. To develop an LC circuit.
3. To find the best combination of capacitor and inductor to get the frequency signal.

1.5 SCOPE OF WORK

The scope of this project is:

1. The frequency range that this antenna tuner can tune is between 3-23MHz.
2. Impedance value to match with the input impedance is almost 50Ω.
3. The tuning time will be between 2-5 seconds.

1.6 PROJECT EXPECTATION

By the end of this project, student is expected to:

1. Develop software system to control the tuner.
2. Develop RF sensing system.
3. Control matching component to change impedance on the transmission line.

1.7 PROJECT REPORT ORGANIZATION

This project report consists of 5 major chapters. Below are the explanations of each chapter:

1. Chapter 2 presents the background of antenna tuner.
2. Chapter 3 is about the details on how the project was formed. It shows the steps to develop the antenna tuner.
3. Chapter 4 covers the project results and discussion. The tuning process is explained in detail in this chapter.
4. Chapter 5 focus on the project conclusion and recommendation for future research.

CHAPTER 2

THEORETICAL REVIEW OF THE PROJECT

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past researches related to antenna tuner and the component needed to build the tuner. This chapter is also focused on the history of antenna tuner development. For this project, the antenna tuner that will be built is automatic antenna tuner. From the articles and journals, the idea of automatic antenna tuner operation is develop.

2.2 AUTOMATIC ANTENNA TUNER

Automatic antenna tuner is the device that is use to tune the antenna to get the signal. The term automatic means that the tuner can tune the antenna by matching the impedance automatically when connected to the radio transmitter. It is a system able to transform the unpredictable or badly defined load impedance to well-defined impedance automatically, and it is made up of tunable matching network, an impedance sensor and a control network. The tunable matching network is typically a ladder network while the sensor provides some indication of the tuned antenna impedance. (E. L. Firrao, 2008; A.J. Annema, 2008; B. Nauta, 2008).

A number of automatic antenna tuners can be found in literature. (E. L. Firrao, 2008; A.J. Annema, 2008; B. Nauta, 2008). These can be categorized by either the way adaptation is done or by the way the impedances (or the impedance-mismatch) are measured. Roughly a number of classes can be identified:

- Adaptation methods on analytic computation that assume the impedance can be measured exactly. Usually these methods require impedance measurement at RF-frequencies.
- Adaptation methods that use the sign of the phase difference to tune a reactive component to zero. These methods usually employ RF-phase detectors or Foster-Seeley discriminators and usually are zero-crossing methods.
- Adaptation methods that minimize a pre-specified figure of merit e.g. reflected power or voltage standing wave ratio (VSWR).

2.2.1 Basic Concept of the Antenna Tuning System

The concept of antenna tuning system is shown in Figure 2.1. Tuning is done in two steps which the first step is the imaginary part of the load impedance is tuned to almost zero using a series (or shunt) reactance. The next step is the resulting real part is transformed to the target value (usually 50Ω) with a tunable "transformer". These steps fit well to the low-power impedance measurement method. (E. L. Firrao, 2008; A.J. Annema, 2008; B. Nauta, 2008).

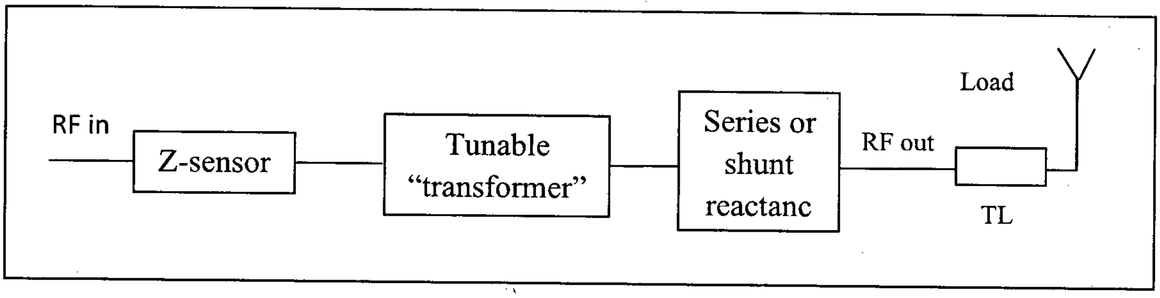

Figure 2.1: Basic concept of automatic antenna tuning system

2.3 IMPEDANCE MATCHING NETWORK

To develop an antenna tuner, impedance matching network is an important part. The term impedance matching is defined as the process of making one impedance look like another. It becomes necessary to match a load impedance to the source or internal impedance of a driving source. A wide variety of components and circuits can be used for impedance matching. Impedance matching networks have important implications for RF receiver performance metrics such as noise, power consumption, and gain. The input and output impedance must be sufficiently matched to the source and the loads impedances.

Impedance matching is needed to provide maximum power transfer between the source of RF energy and its load.

The insertion loss, which is the attenuation of a signal passing through the impedance matching networks should be minimized to decrease the noise susceptibility of the RF signal and to reduce the number of amplifier stages required. The impedance matching network must also be designed to satisfy the power handling constraints imposed by its circuit elements. (Arthur Nieuwoudt, 2008).

There are three types of impedance matching network which are L-network, π-network and T-network. For L-network, the range of impedance transformations possible is limited. However, the addition of a third reactance in principle allows matching to be achieved to any load impedance. (J.R. Moritz, 2000; Y. Sun, 2000). The function of π-network is to match a high impedance source to the lower value to load impedance same as the T-network.

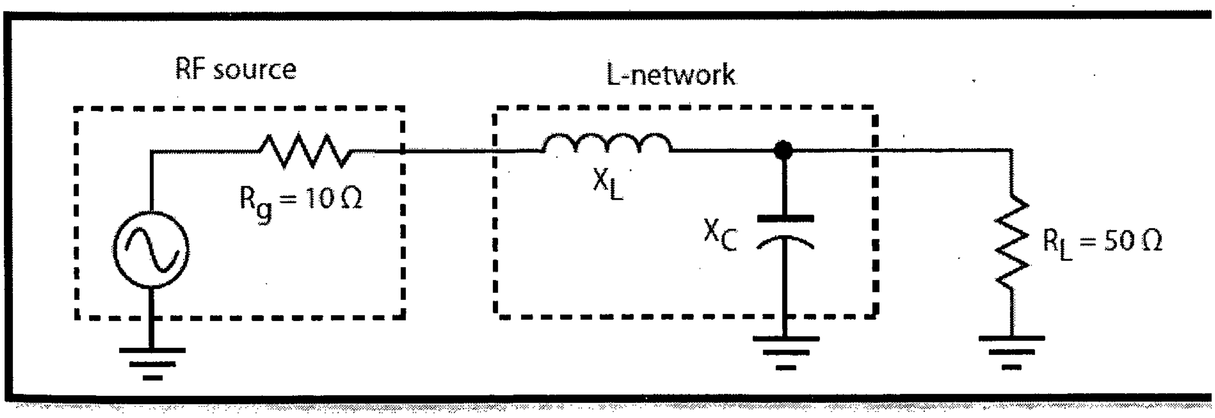

Figure 2.2: Impedance matching circuit for L-network

Figure 2.2 shows L-networks impedance matching circuit. L-networks are useful in matching one amplifier output to the input of a following stage. Another use is matching antenna impedance to a transmitter output or a receiver input. Any RF circuit application covering narrow frequency range is a candidate for an L-network. There are four basic versions of the L-network, with two low-pass versions and two high-pass versions. The lo-pass versions are probably the most widely used since they attenuate harmonics, noise and other undesired signals, as is usually necessary in RF designs. The key design criteria are the magnitudes and relatives sizes of the driving generator output impedance and load impedance.

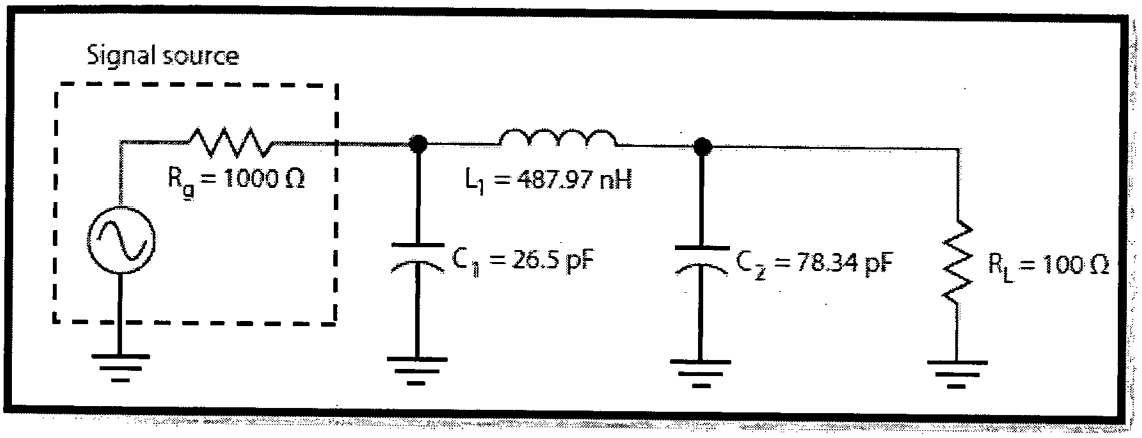

Figure 2.3: Impedance matching circuit for π-network

The basic π-network's (***Figure 2.3***) primary application is to match a high impedance source to lower value to load impedance. It can also be used in reverse to match low impedance to higher impedance. The π-network can be considered as two L-networks back to back. For ***Figure 2.4***, it shows the impedance matching circuit for T-network. It could be represented as two L-network connected together through their shunt component.

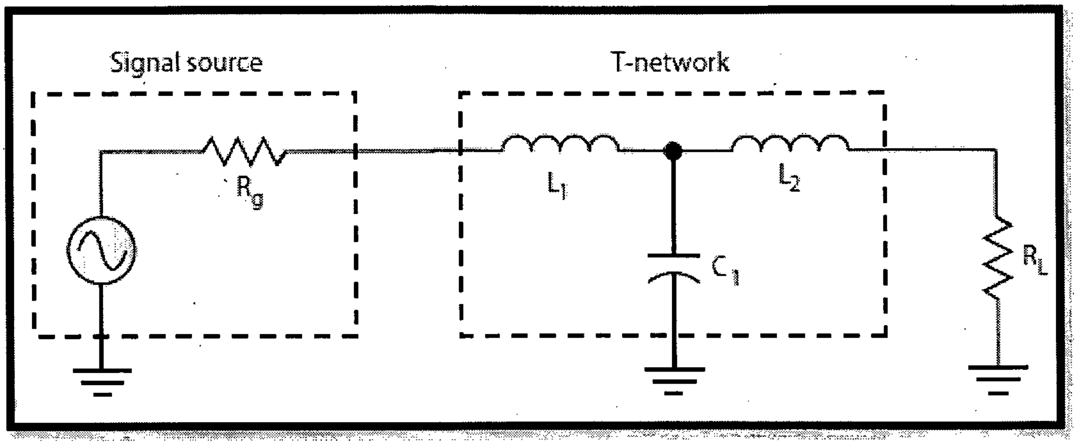

Figure 2.4: Impedance matching circuit for T-network

For the automatic antenna tuner, the tuner automatically adjusts to ensure the best impedance match possible for maximum power transfer. Switchable impedance matching networks utilize passive components with several discrete values to provide impedance matching at several set of frequencies while tunable impedance matching network utilize passive components with continuously adjustable values to provide impedance matching over a continuous frequency range. (Arthur Nieuwoudt, 2008).

2.4 STANDING WAVE RATIO

Standing wave ratio (SWR) is the ratio of maximum amplitude of the standing wave to the minimum amplitude in an electrical transmission line. It is means that SWR is the ratio of the anti-node voltage to the node voltage of the standing wave in the feed line. When the output power is impeded, the waves are called standing. It is means that they are not radiating the way they are supposed to. A low SWR means that the antenna is transmitting a satisfactory amount of RF power instead of sending back to the transmitter. SWR also related to reflection coefficient and the impedances of transmission line and antenna. For the perfect impedance match situation, $\Gamma = 0$ and SWR = 1. It is also can be expressed by 1:1.

$$SWR = \frac{E_{max}}{E_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

$$\text{SWR} = \frac{Vmax}{Vmin} = 1$$

A VSWR measurement of 1:1 would denote a perfect impedance match where there is no voltage standing wave would be present in the signal path. (P.O. Otasowie, 2009; E.A Ogujor, 2009). SWR is used as efficiency measure for transmission line. The standing wave ratio must be less than 1.5:1 to get the perfect impedance matching. SWR can be measured using SWR meter. Usually SWR meter is used to check the new antenna system for standing wave ratio to make sure they are functioning properly. (Emeritus Hans Schroeder, 2005; Nick Luther, 2005).

2.5 TRANSMISSION LINE BASIC THEORY

The transmitter that generates RF power to drive the antenna usually located at some distance from antenna terminals. The connecting link between transmitter and antenna terminals is called transmission line. Its purpose is to carry RF power from one place to another. There are two main categories of transmission lines which are cables and waveguides. Both types work well for efficiently carrying RF power.

2.5.1 Cables

For frequencies higher than HF, RF cables are almost exclusively coaxial cables. Coaxial cables have a core conductor wire surrounded by a non-conductive material called dielectric. The dielectric is surrounded by encompassing shielding which is made of braided wires. Dielectric prevents an electrical connection between the core and the shielding. The outer casing is made of PVC material which used to protect the coax cable. The inner conductor carries RF signal. While the outer shield prevents RF signal from radiating to the atmosphere, and also prevents outside signals from interfering the signal carried by core.

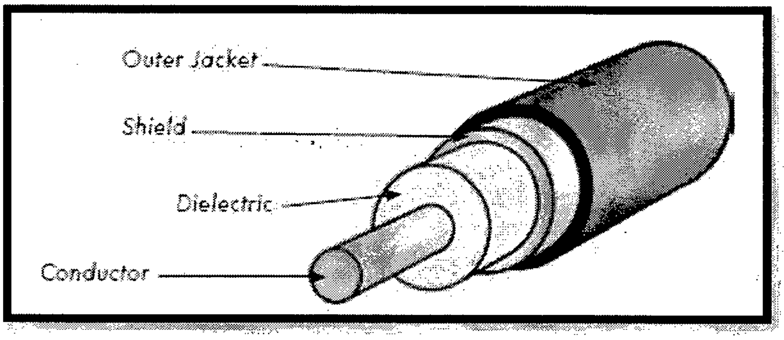

Figure 2.5 Coaxial cable

2.5.2 Waveguides

Above 2 GHz, the wavelength is short enough to allow practical, efficient energy transfer by different means. A waveguide is a conducting tube through which energy is transmitted in the form of electromagnetic waves. The tube acts as a boundary that confines the waves in the enclosed space. The electromagnetic fields are propagated through the waveguide by means of reflections against its inner walls which considered as perfect conductors.

Cable Type	Core	Dielectric	Shield	Jacket
RG-58	0.9 mm	2.95 mm	3.8 mm	4.95 mm
RG-213	2.26 mm	7.24 mm	8.64 mm	10.29 mm
LMR-400	2.74 mm	7.24 mm	8.13 mm	10.29 mm
3/8" LDF	3.1 mm	8.12 mm	9.7 mm	11 mm

Table 2.1 Various sizes of common transmission lines

2.6 MICROCONTROLLER

Microcontroller is a very common component used in electronic system. For example, microcontroller used in mobile phone, printer, security alarm system, television, radio and so on. Microcontroller is a device that integrates some components of microprocessor system into a single microchip. Microcontroller is the combination of CPU core, memory (ROM and RAM) and parallel digital I/O. Microcontroller also combine other devices such as timer module, serial I/O and ADC (allow the microcontroller to accept analog input data). The figure below show some microcontroller device and the different sub units integrated onto the microcontroller chip.

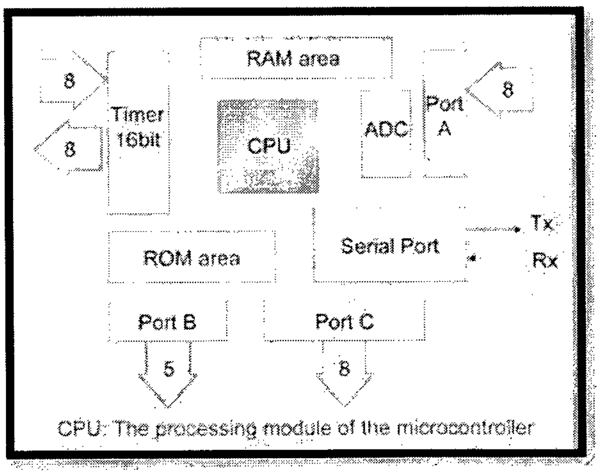

Figure 2.6 A single chip microcontroller

2.6.1 Memory in Microcontroller

The memory in microcontroller is divided into ROM and RAM, with typically more ROM than RAM. The amount of ROM type memory is between 512 bytes and 4096 bytes. But, some 16 bit microcontrollers have as much as 128 Kbytes of ROM type memory. ROM type memory is used to store the program code. It can be ROM, EPROM or EEPROM.

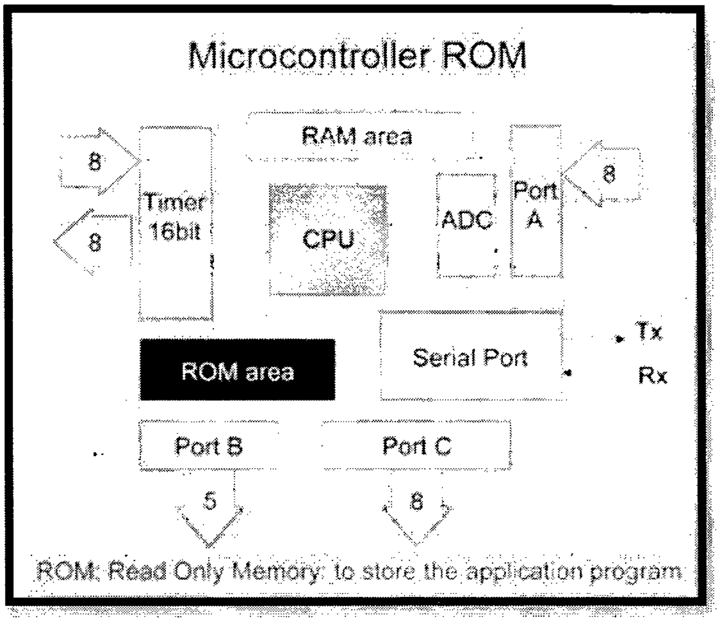

Figure 2.7 Microcontroller ROM

The amount of RAM type memory is usually similar which is between 25 bytes to 4Kbytes. RAM memory type is used for data storage and stack management tasks. It is also used for register stacks.

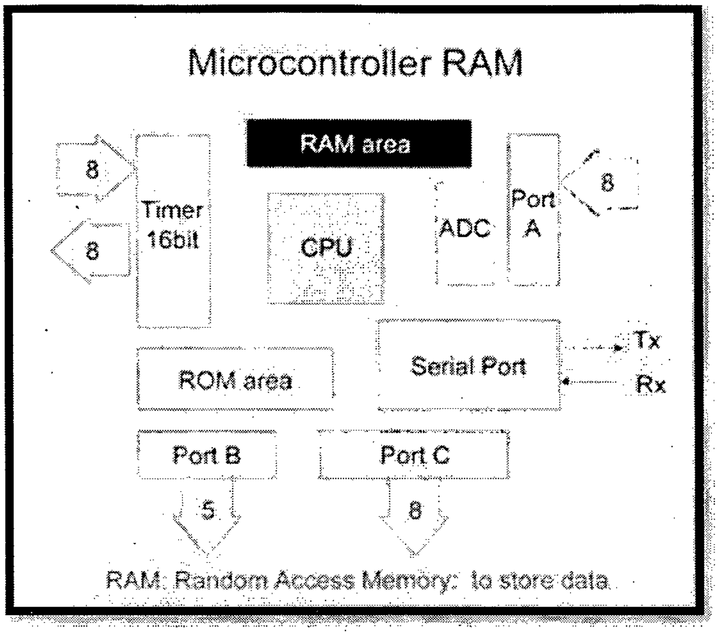

Figure 2.8 Microcontroller RAM

2.6.2 The I/O Ports

The digital I/O ports mean the microcontroller interfaces to the environment. Digital I/O tends to be grouped into byte (8 digital bits) that can be configured as input or output bits. The number of I/O port bits varies depending upon the size of the microcontroller. There is a very simple 8 bit microcontroller which has 4 bits of I/O. For a high end range microcontroller can have 33 bits of I/O ports.

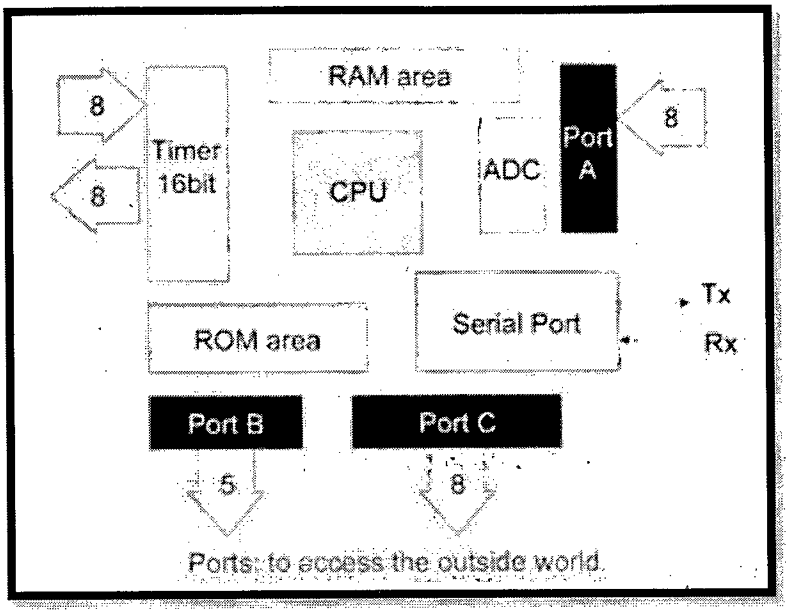

Figure 2.9 Microcontroller I/O ports

2.7 BASIC OPERATION OF LC CIRCUIT

LC circuit which is also called a tuned circuit consists of inductor (L) and capacitor (C). When connected together, they can act as an electrical resonator, an electrical analogue of a tuning fork, storing energy oscillating at the circuit's resonant frequency. LC circuits are used for generating signals at particular frequency or picking out a signal at particular frequency from more complex signal. There is no dissipation of energy due to existence of resistor.

LC circuit can store electrical energy oscillating at its resonant frequency. Capacitor stores energy in electric field (E) between its plates depends on the voltage across it. While inductor stores energy in its magnetic field (B) depends on current through it. If charged capacitor is connected across an inductor, charge will flow through the inductor, building up a magnetic field around it and reducing the voltage on capacitor. The energy to keep the charge flowing is extracted from magnetic field, which will begin to decline. Then, the current will charge capacitor with a voltage of opposite polarity to its original charge. When magnetic field is completely dissipated, the current will stop and the charge will be stored in capacitor with the opposite polarity. The charge flows back and forth between the plates of the capacitor, through the inductor until internal resistance make oscillations stop. The oscillation frequency is determined by the capacitance and inductance values. There are two types of LC circuit which are series connection and parallel connection.

2.7.1 Series LC Circuit

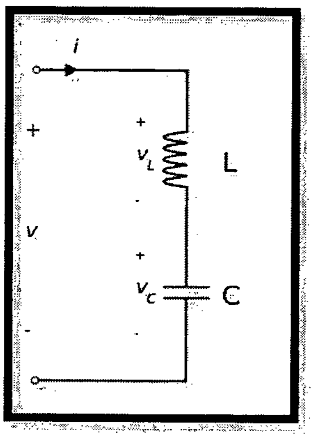

Figure 2.10 Series LC Circuit

In the series LC circuit, the inductor and capacitor are connected in series (***Figure 2.10***). The total voltage, v across the open terminals is simply the sum of the voltage across the inductor and the voltage across the capacitor. The current, *i* flowing into the positive terminal of the circuit is equal to the current flowing through both capacitor and inductor.