CHAPTER 1

INTRODUCTION

1.1 Thermal Management of Electronics

The past few decades have seen an escalation of power densities in electronic devices and in particular microprocessor chips. Together with the continuing trend of reduction in device dimensions, this has led to dramatic increase in the thermal issues within electronic circuits. Thermal management is therefore becoming increasingly more critical and fundamental to ensure that electronic devices operate within their specifications. In order to satisfy the junction temperature requirements in terms of performance and reliability, improvements in cooling technology is required. The task of maintaining acceptable junction temperature by dissipating the heat from the integrated circuit chips is a significant challenge to the thermal engineers.

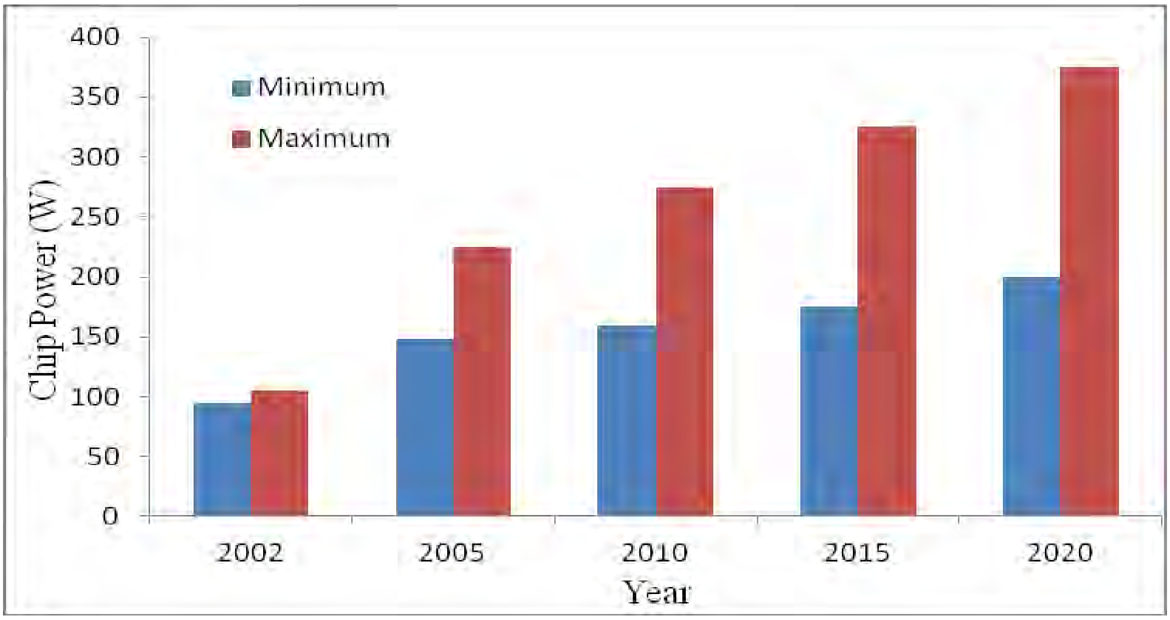

Figure 1.1 High Performance Chip Power Trends [1]

The electronics cooling is viewed in three levels, which are non-separable [1]. First, maintenance of chip temperature at a relatively low level, despite of high local heat density. Second, this heat flux must be handled at system or module level. Finally, the thermal management of the computer machine room, office space, or telecommunication enclosure. The thermal design of the system is influenced by the key drivers like chip size, power dissipation, junction temperature and ambient air temperature.

Semiconductor industries are taking great amount of effort over the years to reduce the size of the devices. With the increase in power dissipation and reduction in the size, the growth in power density is expected to increase further over the next decade as shown in Figure 1.1 and Figure 1.2

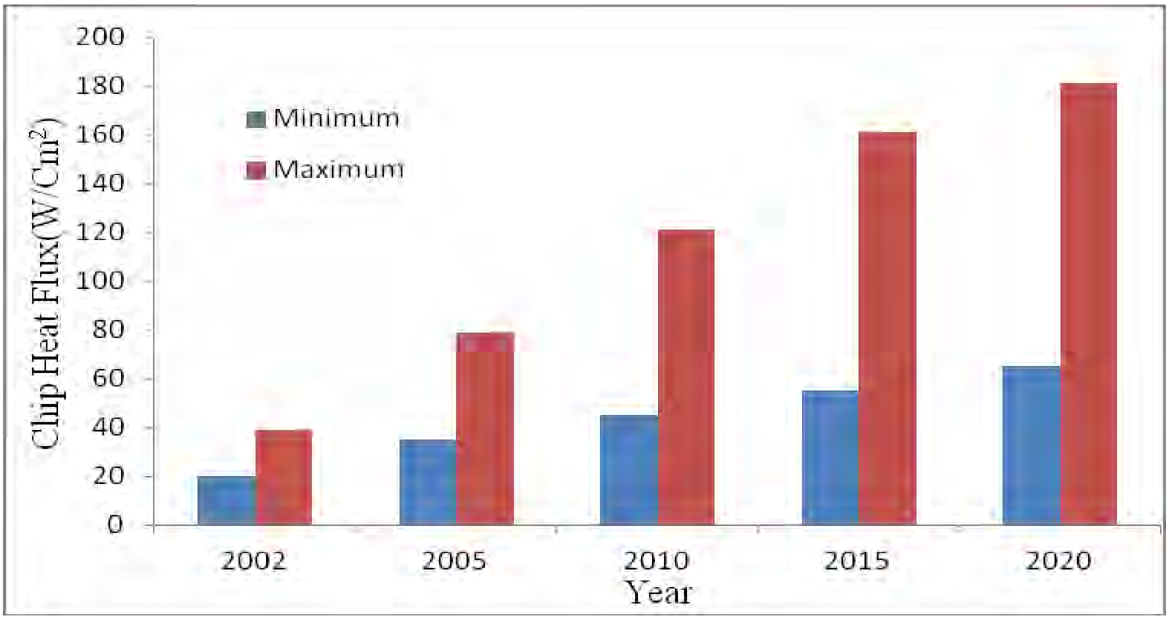

Figure 1.2 High Performance Chip Heat Flux Trends

The increasing power density indicates the thermal management solutions play an important role in determining the future semiconductor device technology.

1.2 Classification of Cooling Methods

In general, cooling methods in electronics [2] are classified into two types:

1. Active Cooling
2. Passive Cooling

1. Active Cooling

Mechanically assisted cooling sub systems are termed as active cooling systems. Active cooling has advantages of high cooling capacity. They provide such an efficient cooling that the systems can be cooled to even below the ambient temperatures.

Air/liquid jet impingement, forced liquid convection, spray cooling, thermoelectric cooling and refrigeration cooling are few active cooling techniques.

2. Passive Cooling

The cooling systems which are not assisted by mechanical equipment are the passive cooling systems. The conventional passive cooling techniques include heat spreaders and heat sinks to the electronic packages. Recent technology development shows the use of thermal energy storage with phase change materials and integration of the heat pipes to the electronic packages.

These are used to achieve high cooling capacity and are ideal for electronic cabinet cooling.

1.3 Different Cooling Methods

The different cooling methods [1] are:

1. Air cooling
2. Liquid cooling
3. Refrigeration cooling
4. Thermoelectric cooling
5. Heat pipes

1. Air Cooling

Air cooling is the simplest method of electronic cooling most widely used in thermal controlfor variety of electronic systems. The advantages of air cooling are its ready availability and ease of application. The air cooling can be done in two ways; one is by natural convection and other by forced convection.

It is common knowledge that air rises as it is heated due to its resulting decrease in density (convection). The air flow resulting from this convection process is referred to as laminar flow. This process provides a natural means of removing heat generated by electronic components.

Advantages of applying natural air cooling include low to no maintenance requirements, no resulting wear and tear, and no noise emission during application. The most prevalent disadvantage of using natural air cooling is that it results in very low levels of cooling.

Air blowers/fans are used in forced air cooling in order to increase the air velocity. This increased velocity aims to produce turbulent air flow rather than a laminar flow, effectively increasing heat dissipation to the surrounding atmosphere.

The advantage of using forced air is that it has a far better cooling effect than natural air cooling. Disadvantages include the high amount of noise produced during application as well as resulting wear and tear.

2. Liquid Cooling

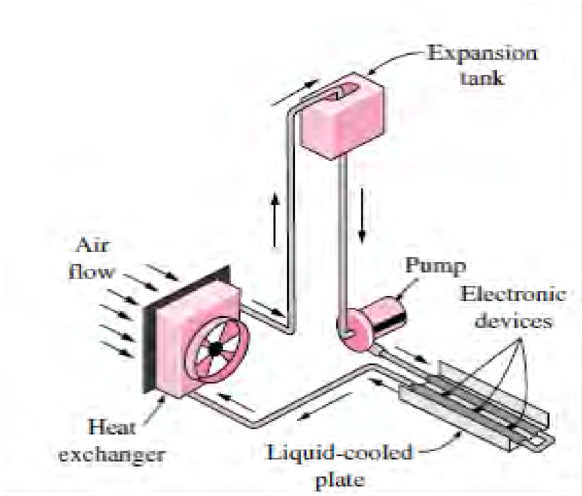

Figure 1.3 Schematic of an Indirect Liquid Cooling System

Liquid cooling is more effective than air cooling for high power electronic applications as the heat transfer coefficients are higher. However, there are some inherent problemssuch as leakage, corrosion, extra weight and condensation in liquid cooling making its scope limited for fewer applications.

The liquid cooling may be of two types. One, the cooling systems where the fluid is in direct contact with the electronic devices and two, where the fluid is not in contact with the electronics directly(Figure 1). Some of the examples of liquid cooling are (1) Single-phase liquid impingement jet cooling, (2) Pool boiling or two phase liquid spray cooling, (3) Indirect liquid cooling using heat exchangers. Theheat transfer from the components to the fluid may be by natural convection or forced convection or pool boiling depending on the temperature levels involved in the system and fluid properties.

3. Refrigeration Cooling

Refrigeration cooling technique is one of the most promising cooling techniques to keep the junction temperature below the maximum operating temperature and handle high heat dissipation applications (Figure 2). The advantages of the refrigeration cooling technique are

(1) To maintain a low junction temperature and at the same time dissipate high heat fluxes

(2) To increase the device speed due to a lower operating temperature and

(3) To increase the device reliability and life cycle time because of a lower and constant operating temperature.

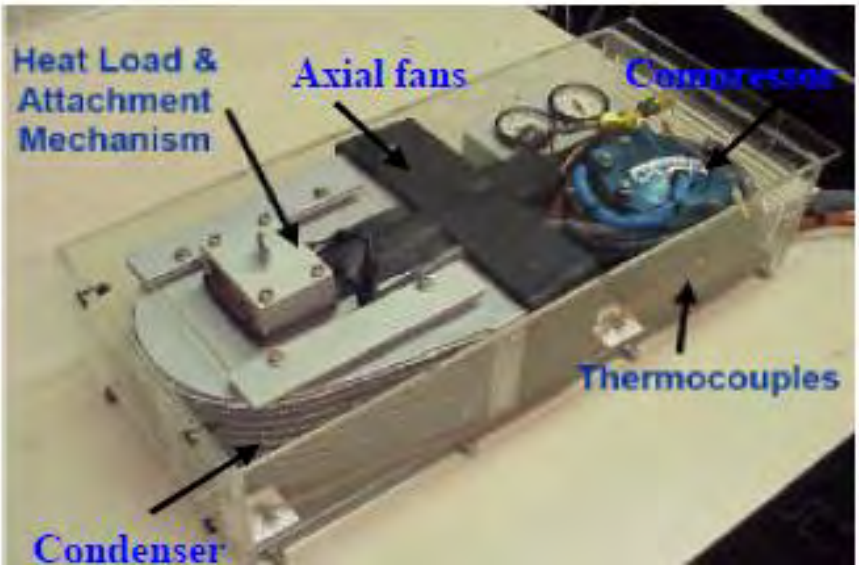

Figure 1.4 Small-Scale Refrigeration Cooling System

Disadvantages of the refrigeration cooling technique are

(1) Increased complexity and cost

(2) Need for additional space to fit the components of the refrigeration system and

(3) Decrease of the system reliability as a result of an additional moving component, i.e., the compressor.

4. Thermo Electric Cooling

The Peltier Effect is one of the three thermoelectric effects. The other two are known as See beck Effect and Thomson Effect. Whereas the last two effects act on a single conductor, the Peltier Effect is a typical junction phenomenon

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. A Peltier cooler, heater or thermoelectric heat pump transfers heat from one side of the device to the other side due to the temperature gradient with the aid of electrical energy (Figure 1.5). Such a device is also known as a Peltier device, Peltier diode, cooling diode, Peltier heat pump, solid state refrigerator or thermoelectric cooler.

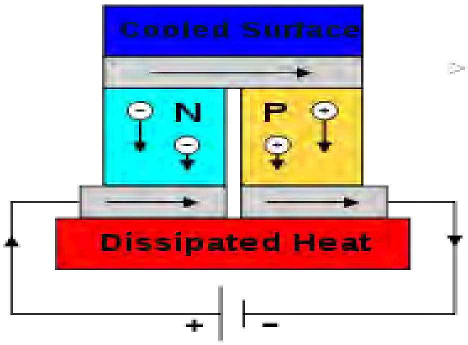

Figure 1.5 Thermoelectric Phenomenon's for Cooling of Electronic Equipment

5. Heat Pipes

A heat pipe is a passive two phase heat transfer device capable of transferring large quantities of heat with a minimum temperature drop (Figure 1.6) Heat pipes, due to their unique physical features, operational characteristics and applications, deserve a special mention in the field of electronics thermal management.

Figure 1.6 Heat Pipe Assembly Used in Mother Board

In the above section different cooling methods employed in the cooling of electronic components are discussed in detail. Among all the cooling methods heat pipes are found to be more suitable. Hence the present work is directed towards developing of a suitable OHP for the electronic cooling application.

Hence in the next section heat pipes are explained in detail rather than any other cooling method

1.4 Conventional Heat pipe

1.4.1Construction and Working

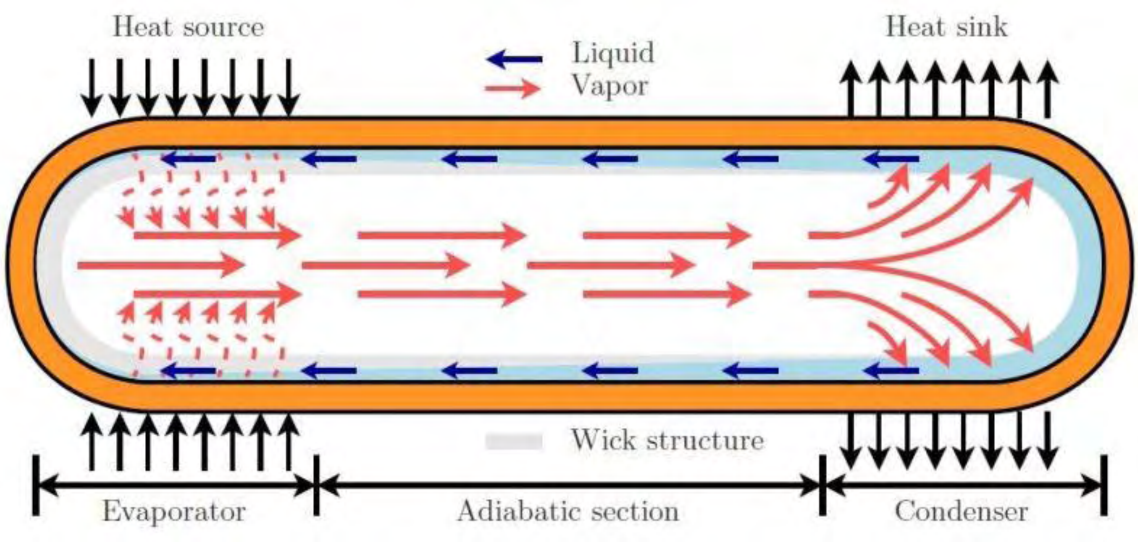

Figure 1.7 Schematic Diagram of Conventional Heat Pipe

The construction and working of conventional heat pipe [3] is as described. The components of a conventional heat pipe are a sealed container, a wick structure and a small quantity of working fluid which is in equilibrium with its own vapor (Figure 1.7). It encompasses three essential parts: an evaporator, an adiabatic transport section and a condenser. A heat flux entering the evaporator, for instance from a hot component, vaporizes any available coolant liquid, thereby absorbing large quantities of heat. The vapor, indicated by the red arrows, travels through the adiabatic transport section to the condenser, propelled by the difference in pressure. In the condenser the vapor condenses as the temperature is lower, releasing its latent heat. This heat can be extracted from the heat pipe by a heat sink. To complete the cycle, the condensed liquid must be pumped back to the evaporator, as indicated by the blue arrows. The fluid return is facilitated by a capillary or wick structure, indicated in gray. The wick structure, saturated with the liquid phase of the working fluid, is able to transport the fluid, due to the capillary pressure caused by the difference in curvature of the liquid menisci. This process will continue as long as there is sufficient pressure to drive the condensate back to the evaporator.

The vapor pressure changes along the heat pipe are due to friction, inertia, evaporation and condensation effects while the liquid pressure changes mainly as a result of friction. The liquid-vapor interface is flat near the condenser end cap corresponding to a zero local pressure gradient at very low vapor flow rates. When body forces are present such as gravitational force, the liquid pressure drop is greater, indicating that the capillary pressure must be higher in order to return the liquid to the evaporator for a given heat load. At moderate vapor flow rates, dynamic effect causes the vapor pressure drop and recovery along the condenser section

1.4.2. Limitations of Conventional Heat Pipes

Conventional Heat pipes are excellent heat transfer devices but their application is mainly confined to transferring small amount of heat over relatively short distances when the evaporator and condenser are at same horizontal level. This limitation on the part of the conventional heat pipes is mainly due to the major pressure losses associated with the liquid flow through the porous structure. Also, there will be viscous interaction between the vapor and liquid phases, called entrainment losses. For the applications involving transfer of large amount of heat over long distances, the thermal performance of the heat pipes is badly affected by increase in these losses. For the same reason conventional heat pipes are very sensitive to the change in orientation in gravitational field. In the top heat mode positions(evaporator at the top, condenser down), the pressure losses due to the mass forces in gravity field adds to the total pressure losses and further affect the efficiency of the heat transfer process.

As a result of these limitations, different solutions involving structural modifications to the conventional heat pipe have been proposed. Some of these modified versions of heat pipe incorporated arterial tube with relatively low hydraulic resistance for the return of the liquid to the heat supply zone while others provided spatial separation of the vapor and liquid phases of a working fluid at the transportation section.

Though these heat pipes are able to increase heat transport length and transfer significant amount of heat they are very sensitive to orientation in the gravity field. The advantages provided by the spatial separation of the transportation line and usage of non-capillary artery tube are combined together in loop heat pipes (loop schemes) popularly known as Oscillating Heat Pipes (OHPs). As a result, this loop scheme makes it possible to develop heat pipes with higher heat transfer characteristics while maintaining normal operation at any orientation in the gravity field.

1.5 Oscillating Heat Pipes (OHP)

Oscillating Heat Pipes (OHPs), a concept proposed by Akachi [1990] [4] seems to meet all the present day cooling requirements. OHPs are highly attractive heat transfer elements, which due to their simple design, cost effectiveness and excellent thermal performance may find wide applications. These heat pipes are able to overcome some limitations of conventional heat pipes. (e.g., the capillary and entrainment limits). Although grouped as a subclass of the overall family of heat pipes, the complexity of thermo-hydraulic coupling is distinctly unique. OHPs are essentially non equilibrium heat transfer devices.

1.5.1 Construction and Working Principle of OHP

Oscillating, or oscillating heat pipes comprise a tube of capillary diameter, evacuated and partially filled with the working fluid. Oscillating heat pipe configurations are shown schematically in Figure 6. Typically, a Oscillating heat pipe comprises a serpentine channel of capillary dimension, which has been evacuated, and partially filled with the working fluid. Surface tension effects result in the formation of slugs of liquid interspersed with bubbles of vapor

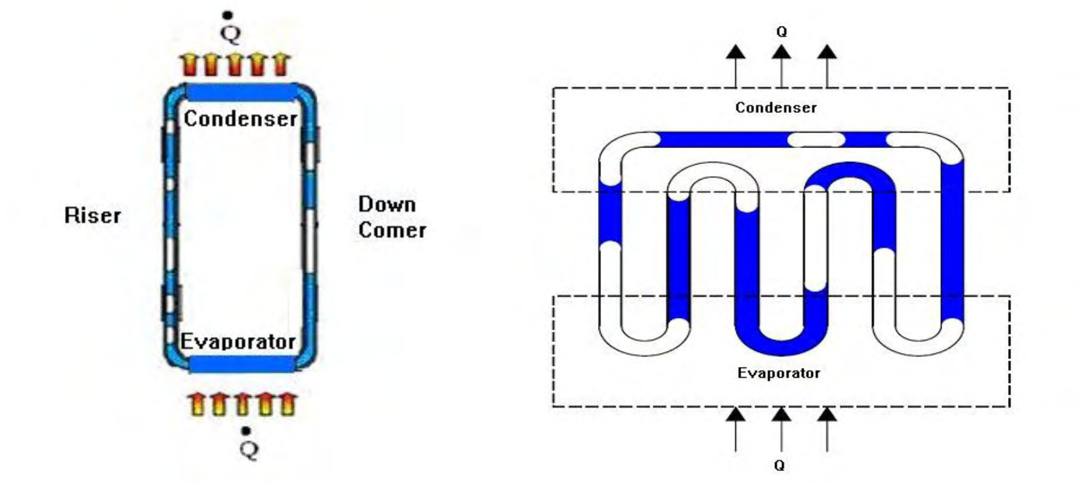

Figure 1.8 Schematics of a Single Loop and Multiple Loops Oscillating Heat Pipe

A OHP is a device consisting of a tube of small diameter. The device may be of single loop or with multiple loops (Figure 1.8)

A multiple loop OHP consists of a small diameter tube that crosses a condenser and evaporator region multiple times. The tube is filled with a working fluid such that only the fluid and its vapor phase exist. The tube's inner diameter must also be small enough for the capillary forces of the fluid to create vapor bubbles (plugs) and liquid slugs. Thus the vapor plugs completely block the flow of the liquid. This keeps the plugs and slugs in a linear arrangement within the tube as seen in Figure 6. Heat transfer in an OHP is associated with liquid and vapor motions induced by the pressure difference. Evaporation at a higher temperature in the evaporator produces a higher vapor pressure. The same is the case for the condenser where condensation and reduced temperature at the condenser cause a decrease in pressure. The increased pressure in the evaporator and decreased pressure within the condenser causes a pressure imbalance. Due to the random arrangement of liquid slugs and vapor plugs within an OHP, this pressure imbalance forces the hot vapor and liquid from the evaporator to the condenser. Subsequently, the cool vapor and liquid flows from the condenser to the evaporator, resulting in an oscillating motion. The oscillating motion consists of small rapid movement within portions of the tube and in some cases bulk motion through the entire OHP.

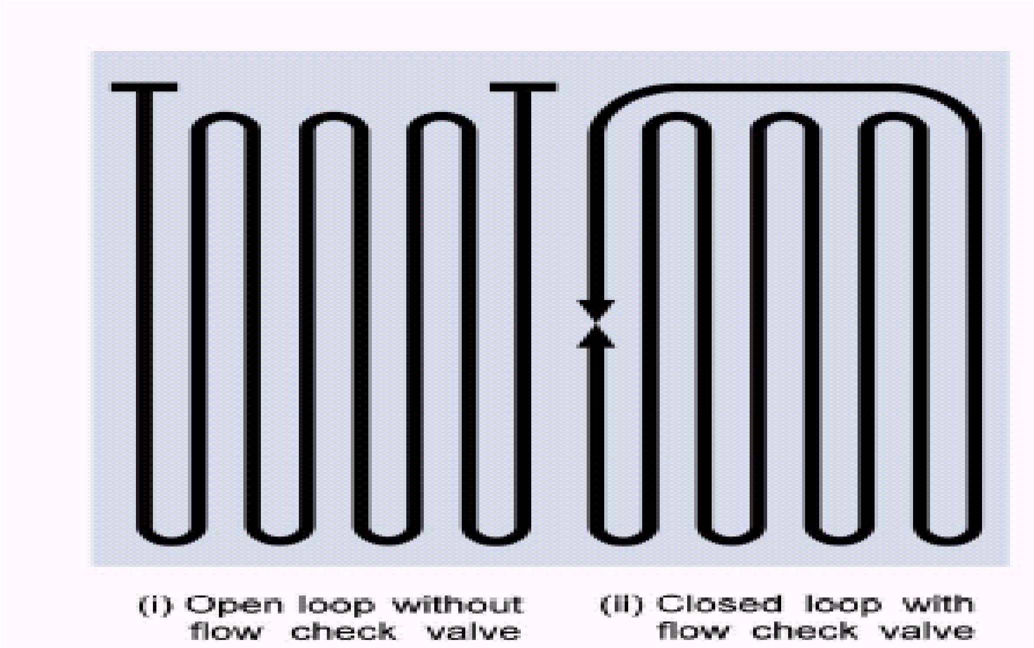

Figure 1.9 Open Loop and Closed Loop Arrangement of OHP

There are two general types of OHP named as open and close loop OHP (Figure 1.9). The closed loop OHP is a continuous tube in which the fluid passes through the evaporator and condenser multiple times continuously. The open loop OHP is similar except that the two ends of the tube are sealed. Generally, close loop OHPs perform better than open loop.

Most of the OHPs are made of copper, aluminum and/or glass. Copper and aluminum with their high thermal conductivity are better suited for OHP. Glass has been used in several experiments for flow visualization.

The parameters affecting the performance of closed loop OHP have been summarized by Groll and co-workers as [5]

- Working fluid
- Internal tube diameter
- Total tube length
- Length of condenser, evaporator and adiabatic sections
- Number of turns or loops
- Orientation.

1.5.2 Applications of OHP

Some of the typical applications of OHP [6] are:

- Laptop Computers
- High-performance processors (CPU, GPU)
- Aerospace; space craft temperature equalization, component cooling
- Low maintenance/high reliability applications
- Noise-sensitive environments where heat can be dissipated to a larger remote heat sink

1.6 Summary

In this chapter, the importance of cooling, in modern electronic devices are discussed. Different cooling methods are discussed in detail. The importance of heat pipes in cooling of electronic components is established. The working principle of conventional heat pipe is explained along with its limitations. Then the working and applications of Oscillating heat pipes are explained in detail. In the next chapter, literature survey related to OHP is presented.