CHAPTER - V
5.0 SUMMARY CONCLUSION AND FUTURE SCOPE

The thesis work addresses temperature behavior and compensation technique of PIN diode, Schottky barrier diode and FET based microwave circuits. The research work proposed and successfully demonstrates a novel temperature compensation technique, based on optimum bias load line technology, which compensates temperature behavior of PIN and Schottky barrier diode based microwave circuits, which is more accurate, simpler and more reliable than previous reported circuits. The work shows that the same technology is also applicable for temperature compensation of light emitting diode. The thesis work also presents and demonstrates practical and theoretical design details of the temperature compensation mechanisms of various microwave circuits and sub systems based on MESFET, HEMT, PIN diode and Schottky barrier diode.

5.1 SUMMARY and CONCLUSION

A hitherto unexplored mathematical property of PIN diode, Schottky barrier diode and Light Emitting Diode has been discussed. This property is exploited in a simple and easily adjusted control circuit that provides excellent setting accuracy and temperature stability. It is shown that this approach can be used for a wide range of practically available diodes. This circuit uses no separate temperature sensor or compensating mechanism, but responds directly to the junction temperature of the diodes. This prevents any errors caused by temperature gradients, or by self-heating of the diodes due to high RF levels. The proposed novel technology provides setting and temperature accuracy, which is
better than accuracy available from MMIC based passive digital attenuator circuits.

## 5.1.1 Temperature Dependency of Bandgap Potential

Temperature compensation technique of PIN diode and light emitting diodes based on the optimum bias load line technology, where open circuit voltage of the control circuit depends upon bandgap potential of the semiconductors. All the above discussion assumes that band gap potential is independent on temperature or any other environment condition. However, bandgap potential of semiconductor is a function of temperature and pressure. At room temperature and under normal atmospheric pressure, the values of the bandgap are 1.12 eV for Si, and 1.42 eV for GaAs. These values are for high-purity materials. For highly doped materials, the bandgaps become smaller. Experimental result shows [1] that the bandgaps of most semiconductors decreases with increasing temperature. The bandgap approaches 1.17 eV, and 1.519 eV, respectively for Si and GaAs semiconductor at 0 K. The variation of bandgap with temperature can be expressed approximately by a universal function:

\[ E_g(T) = E_g(0) - \frac{\alpha T^2}{T + \beta} \]  

(5.1)

where \( E_g(0) \), \( \alpha \) and \( \beta \) are 1.17 eV, 4.73\( \times 10^4 \) and 636 K for Si and 1.519 eV, 5.405\( \times 10^4 \) and 204 K for GaAs respectively.

Near room temperature, the bandgap of Si decreases with pressure, \( dE_g/dP = -2.4 \times 10^6 \) eV/(kg/cm\(^2\)). The bandgap of GaAs increases with pressure, \( dE_g/dP = -12.6 \times 10^6 \) eV/(kg/cm\(^2\)).
5.1.2 Temperature Dependency of Schottky Barrier Height

Temperature compensation technique of Schottky barrier diodes based on the optimum bias load line technology, where open circuit voltage of the control circuit depends upon Schottky barrier height ($\phi_B$) of the metal-semiconductors junction of the diode. The change in the Schottky barrier height [52] with temperature is given by:

$$\phi_B(T) = \phi_B(T_o) + m[E_g(T) - E_g(T_o)]$$  \hspace{1cm} (5.2)

where $m$ is in between 0 to 1, depending upon the surface state energy level.

Thus, Schottky barrier height decreases with the increase of temperature as of bandgap potential on the semiconductor.

5.1.3 Temperature Dependency of Bias Resistor

Temperature coefficient of bias resistors contribute to the temperature coefficient of RF performance of the diode based circuits. Moreover, on-

![Diagram: Temperature Controlled Thermal Chamber]

Fig.-5.1: Measurement to consider temperature dependency of analog-switch, resistor, $E_g$, $\phi_B$

resistance of the analog switches used in the driver circuit for stepwise control of the RF performance has also some temperature coefficient. Figure-5.1 shows the
schematic block diagram of a diode based circuit. The driver circuit contains analog switch and series resistor, both have finite temperature coefficient. To determine the optimum open circuit voltage of the circuit, the voltage and current of the circuit is measured at point 'C' instead at the diode terminal point 'A'. Value of the resistor R is kept approximately equal to the actual value required for the circuit. The diode (PIN, Schottky or LED) based circuit, analog switch and the biasing resistor are all kept in the temperature controlled thermal chamber as shown in the figure. Three sets of voltage and currents are measured at three different temperatures (two extreme operating temperatures and another at the middle of the operating temperature) of the chamber, adjusting voltage/current to the circuit for same performance, and are plotted as shown in the Figure-5.2. The load line will be the best fitted straight line passing all these three points. The intercept of the load line with the voltage axis will be the optimum open circuit voltage of the bias network and inverse slope will give the extra resistor value required which will be algebraically added to the resistor R.

The presented practical procedure takes into account the temperature coefficient of the analog switch as well as bias resistor since measurement reference point taken after these components.

Fig.-5.2: Plot of load line
Today, very precession voltage source, based on the bandgap reference are available with excellent temperature stability. Thus, the above procedure with the temperature stable voltage source provides highly accurate temperature stable performance of the diode (RF performance of PIN and Schottky barrier diode and illumination of LED) based circuits.

The proposed optimum bias load line technology for PIN and Schottky barrier diode definitely solve the problems of temperature variation of RF performance of the diode based circuits. RF circuit manufactures definitely encouraged to use PIN diode and Schottky barrier diode for dynamically RF signal control circuit such as attenuator, phase shifter linearizer, etc. Similarly, using optimum bias load line technology, lighting industry will provide temperature compensated LED illumination without increasing circuit complexity.

5.1.4 Self-Heating and Thermal Runaway

The proposed driver circuits for diode based circuit uses no separate temperature sensor or compensating mechanism, but responds directly to the junction temperature of the diodes. This prevents any errors caused by temperature gradients, or by self-heating of the diodes due to high power dissipation of the diode.

In case of fixed current bias condition, the device current remains constant irrespective of the diode temperature. However, when diodes are operated under temperature compensation condition, the diode current will increase with the increase of diode temperature this will further increase the diode temperature and diode current. This effect may cause thermal runaway of the device. Though, the series resistance of the bias network limit the current to the diode, for more precaution, it should be ensured that the device operation is within the limited
temperature variation environment to keep the device current and power
dissipation within the allowable limit.

5.2 FUTURE SCOPE OF THE WORK

The thesis work invented and successfully demonstrated the “optimum bias
load line technology” for achieving temperature invariant performance of the
junction diode-based circuits. Although optimum bias load line technology solve
the temperature variation problem of the diode-based circuits, there is no such
type of technology evolved for microwave transistor based circuits. As discussed
in the previous chapters that many ECPs are function of temperature and these are
also vary from one device to another device. Thus, in the design phase it is nearly
impossible to incorporate accurate temperature compensation circuit to meet the
performance requirement over the broad operating temperature environment.
Though, the thesis work proposed and demonstrate the use of separate gain
variation block to compensate the overall gain variation of the amplifier it is not
suitable to compensate the output power variation of the power amplifier.
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