OSCILLATOR COMPENSATION CIRCUIT FOR 27 MHz

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By

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LIST OF SYMBOLS AND ABBREVIATIONS

PTAT	Proportional to Absolute Temperature
CTAT	Complementary to Absolute Temperature
ZTC	Zero Temperature Coefficient
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
BJT	Bipolar Junction Transistor
SiC	Silicon Carbide
RC	Resistor and Capacitor Network
NMOS	N-Channel MOSFET
PMOS	P-Channel MOSFET
ADC	Analog to Digital Convertor
I_D	Drain Current
μ_n	Mobility of Electron in Channel
V_{th}	Threshold Voltage
V_{GS}	Gate to Source Voltage
V_{DS}	Drain to Source Voltage

LITAR PENGAYUN PAMPASAN 27 MHz

ABTRAK

Litar pengayun menghasilkan gelombang kotak yang mempunyai frekuensi 27 MHz direka dengan mengguna 50 nm MOSFET bermodel BSIM 4. Pengayun ini dapat menangani tahap suhu dari -25℃ hingga 80˚C. Perisian LTspice digunakan untuk mereka litar dan simulasi dijalankan bagi litar ini. Teknik pengimbangan kesan suhu dapat dijanakan melalui arus elektrik yang berkadar dengan suhu mutlak (PTAT) dan arus elektrik pelengkap dengan suhu mutlak (CTAT). Arus elektrik dijanakan dengan aplikasi teknik pengimbangan suhu yang mampu bertahan suhu pada julat -25℃ hingga 80℃ tanpa gangguan. Litar arus elektrik digunakan sebagai sumber arus elektrik dalam perbezaan pengamplifikasi. Peranan perbezaan pengamplifikasi adalah sebagai pengayun yang dapat menjana gelombang mempunyai frekuansi 27 MHz. Litar sumber arus elektrik merupakan sasaran utama untuk aplikasi teknik pengimbangan suhu. Voltan yang dibekalkan kepada seluruh litar adalah 1V. Litar ini dapat menghasilkan gelombang kotak dengan perubahan frekuensi sebanyak 6.96% dalam julat suhu tersebut.

OSCILLATOR COMPENSATION CIRCUIT FOR 27MHz

ABSTRACT

A 27 MHz oscillator circuit is designed by using 50nm MOSFET model BSIM 4. It able to generate 27 MHz square wave. This oscillator able to compensate temperature from -25˚C to 80˚C. LTspice software is used to design and run simulation for this circuit. Temperature compensation technique involved cancellation effect of proportional to absolute temperature (PTAT) current source with effect of complementary to absolute temperature (CTAT) current source. Current references circuit is created from temperature compensation technique which able to withstand for temperature range -25˚C to 80˚C without deviation. The current references circuit is used as tail current for differential amplifier. Role of the differential amplifier is becoming an oscillator which able to generate 27 MHz square waves. Tail current of the differential amplifier is major target to be compensated from temperature which helps to maintain output characteristic of the oscillator. Voltage supplied to whole circuit is 1 V. This circuit is able to produce square wave with maximum frequency variation of 6.96% along the temperature range.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Oscillator provides clocking signal for many electronic applications[1]. Current reference circuit plays an important role in analog and mixed-signal systems. Commonly, analog and mixed-signal system that involved current reference are digital to analog convertor (D/A), analog to digital convertor (A/D), operational amplifier, oscillator, digital signal processing and so on[2][3]. Moreover, duty cycles of the oscillator can be generated from circuit of current reference[2][4][5][6].A stable and temperature compensation current reference circuit is needed to ensure stability of oscillator.

Temperature compensation technique mainly consists of two types. Firstly, the temperature compensation technique is bandgap reference technique. This technique is using proportional to absolute temperature (PTAT) current and complementary to absolute temperature (CTAT) current to resist temperature effect on the circuit of current reference[4][7]. Normally, this technique can be implemented through base-emitter voltage (V_{BE}) characteristic on bipolar transistor[2][4]. PTAT and CTAT also can be developed using MOSFET properties[7].

Another common temperature compensation technique is zero temperature coefficient (ZTC) biasing. In this technique, gate voltage of MOSFET is biased at ZTC point. So, investigation on the common operation of gate voltage at different temperature value of MOSFET is conducted to determine ZTC value. With that, MOSFETs are biased at ZTC and current reference with temperature compensation can be achieved[2][3].

Besides that, oscillator can be designed in many ways. Normally, oscillator involved with capacitor and inductor to integrate feedback. Inductive and capacitance load is involved with MOSFET to create switching circuit to generate clock signal[8]. Relaxation oscillator with integrated error feedback to generate clock and temperature compensation depends on resistor characteristic[1]. Combination of ring oscillator and current reference with temperature compensated is another way to develop temperature compensated oscillator[5][6].

Oscillator is widely used in many application. However, temperature compensation technique needed to ensure clocking signal function accurately with temperature changes effect.

1.2 Problem Statement

Generally, there are many ways to develop oscillator and temperature compensation technique. Switching phenomena in MOSFET can use to generate oscillation. SiC (Silicon Carbide) able to provide high switching frequency in high temperature and high voltage. This can be done by modelling the parasitic elements in MOSFET such as parasitic inductance, capacitance and resistance[8]. .Although it is a simple and easy method to generate oscillation, this switching technique high depends on material characteristic of SiC. This paper concentrate on material characteristic on SiC but not using MOSFET model in the market. It hard to fabricate inside integrated circuit.

Three stage ring oscillator is another method to generate clocking signal[5]. This paper propose process and temperature compensation technique for the ring oscillator. Temperature compensation technique is using the relation between resistor characteristic, charge mobility and threshold voltage. Then, current source with temperature compensated is provided to the ring oscillator. It is using BSIM model as well for circuit design. However, this paper required involved two major components which are resistor and MOSFET for temperature compensation. This paper is using external resistor for temperature compensation technique but does not highly utilize MOSFET for temperature compensation technique.

Relaxation oscillator with temperature compensation is presented in 90nm CMOS[1]. This paper is using relaxation oscillator which involved operation amplifier (Op-Amp), comparator, buffer, S-R latch, resistor and capacitor. This involved too many building blocks in the circuit. It is quite complex to realize oscillation because it circuit involved many building block. Op-Amp is designed using 90nm CMOS model. However, S-R latch designation has avoided and no details about S-R latch. Suppose S-R latch is built from transistor, temperature effect still occur.

1.3 Objective

There are two main objectives in this project which are:

1. To design 27MHz oscillator circuit which able to withstand temperature range of -25℃ to 80℃.
2. To develop temperature compensation technique current source for the oscillator which can handle temperature range of -25℃ to 80℃.

1.4 Scope of Research

The project focus on developing temperature compensation oscillator technique. The main focus of the project is listed as following:

1. There are many types of temperature compensation method. Temperature compensated current source technique by using bandgap reference will be developed.
2. The oscillation method will using differential amplifier and define frequency adjustment.
3. The circuit is fully using 50nm MOSFET from model BSIM 4.

1.5 Thesis Outline

This report consists of five chapters. The report begins in Chapter 1 with introduction of the project. This chapter describes background, problem statement, objective and scope of research and thesis outline.

Chapter 2 is about literature review of temperature compensation technique and oscillation circuit. Literature review explains type of techniques used for temperature compensation and theories behind these techniques. Then, realization of oscillation in different methods is explained.

Chapter 3 describe methodology of the proposed temperature compensated oscillator. This project explains proposed temperature compensation technique and oscillation method. Overall block diagram of the circuit to present overview of working principle in the circuit. Project flowchart is involved to present the decisions and steps go through to complete this project. The development of temperature compensation technique and oscillation are fully discussed in this chapter.

Chapter 4 is result and discussion of the project. The simulation result of the circuit is shown and recorded. The simulation data will be tabulated and further analysis will be conducted in this chapter. Performance of the circuit will be verified and discussion on the circuit will be done as well.

Lastly, Chapter 5 is the conclusion of this project. The conclusion and review of the limitations of the project will be made. Future work is discussed to find out the solution to overcome the limitation of the project in this chapter.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The study research on temperature compensation technique for current reference and oscillation method have been done tremendously in the past. Many researchers have developed different ways of temperature compensation technique and oscillation method.

There are a number of techniques and methods have been proposed. Each of them have their superiorities and drawback.

Basically, temperature compensation techniques for current reference built from commonly used techniques which are bandgap reference and zero temperature coefficient biasing. Besides that, there are still another technique but fundamental is built from bandgap reference. Temperature compensation technique will be discussed on Section 2.2. Furthermore, oscillation method with compensated temperature will discuss on Section 2.3. Basic theory and working principle will discuss in that section. The reason of literature review on temperature compensation technique and temperature compensated oscillator are conducted in same time because current reference is correlated with building block of oscillator.

2.2 Temperature Compensation Technique for Current Reference

Normally, bandgap reference and zero temperature coefficient (ZTC) are common technique that used to develop temperature compensation technique. Extension of these two common technique can further develop temperature compensated current reference and oscillator.

2.2.1 Bandgap Reference

The bandgap reference is using current changes with temperature phenomena to develop temperature compensation current reference. Current with proportional to absolute temperature (PTAT) effect which increase linearly with increase temperature is known as positive temperature coefficient current. While current with complementary to absolute temperature (CTAT) effect which decrease linearly with increase temperature is known as negative temperature coefficient. Since these two current temperature coefficient properties are work in opposite way, combination of positive and negative coefficient able to cancel out temperature effect to get zero temperature coefficient[2][4][7] [9].

Besides that, compensation technique can realize with using PTAT or CTAT current only. It means either using PTAT current only or CTAT current to develop compensation temperature technique. By using PTAT current source to compensate temperature effect of constant current source, this compensated current source will provide to ring oscillator for generating clock signal[6]. Normally PTAT current circuit can be developed through BJT, controls voltage difference of base and emitter (V_{BE}) able to create PTAT current[2][4][6]. This is because depletion region of p-n junction in BJT is depends on thermal voltage. As V_{BE} remains constant, BJT can will allow more current pass through as temperature increase. This because when temperature increase, thermal voltage will increase and depletion region will decrease. PTAT current circuit can be created by using polysilicon resistor and N-well resistor to create a bootstrapped current reference source. Value of resistance of polysilicon resistor and N-well resistor is defined by mathematics calculation based on the equation of the fractional temperature coefficient[10].

Although PTAT and CTAT current cancel each other effect by adding together, PTAT subtracts CTAT will increase slope of deviation. However, using this slope of deviation can increase slope of PTAT. The slope of PTAT is implemented to temperature sensor and voltage of temperature sensor read by ADC. The value of ADC will be sent to digital circuit. Digital circuit will control capacitor to calibrate frequency of crystal oscillator[11]. By this oscillator will regain to original frequency, this technique not only involved bandgap reference but also combine with ADC, sensor and digital circuit.

Besides that, bandgap references not only using BJT but can also using MOSFET to generate voltage references or current references to cancel temperature effect[7]. Since, threshold voltage is changing according to temperature. This is because threshold voltage depends on bandgap voltage as well. This characteristic can be used to generate voltage references. Since MOSFET involved, CMOS subthreshold voltage reference can be developed. This involved operational transconductance amplifier (OTA) and reference voltage core circuit. MOSFET in voltage core circuit will works in subthreshold region. Thermal voltage equation will be substituted to drain current equation for investigate the relationship between gate voltage and temperature. Then, OTA helps to create voltage references by offset influences of temperature coefficient [12].

By using threshold voltage characteristic, temperature compensation current source can be developed as well. CTAT and PTAT current source can be developed by using threshold voltages as references. Based on the drain current equation, proper biasing width to length ratio can cancel out charge mobility effect. Hence, the drain current will highly depends on threshold voltage. This can done by further mathematics analysis. CTAT can developed through self-biasing circuit and PTAT can be developed by letting one MOSFET operated in triode region mode in self-biasing circuit[7].

2.2.2 Zero Temperature Coefficient

Zero temperature coefficient (ZTC) point means transistor at biasing voltage point in which it has same operation voltage along the temperature range. Assume that NMOS in saturation mode, its drain current is given by

$$I_D = \frac{1}{2}\mu_n C_{OX}\frac{W}{L}(V_{GS} - V_{th})^2 \tag{2.1}$$

where I_D is drain current, μ_n is electron charge mobility, C_{ox} is capacitance per unit gate area, W is width of channel, L is length of channel, V_{GS} is gate to source voltage and V_{th} is threshold voltage.

From the equation (2.1), charge carrier mobility and threshold voltage will change according to temperature. Charge carrier mobility and threshold voltage will decrease when temperature increases. Threshold voltage decrease then drain current in MOSFET will increase. While charge carrier mobility decrease, then drain current in MOSFET will decrease. At ZTC point, charge carrier mobility and threshold voltage able cancel each other effects of temperature[2][3]. ZTC point in MOSFET can defined by using mathematics calculation or simulation on software. So, this phenomena able to develop temperature compensation technique.

2.3 Oscillation Method

There are many types of oscillation method. Commonly, temperature compensated oscillator is developed from compensated temperature current source. Compensated temperature current source plays major role in temperature compensation oscillator. Most of the oscillators using capacitor and inductor to create oscillation.

One of the methods is using ring oscillator. Three stage oscillator is using three inverter connected in series in which output of previous inverter fetch into input of next inverter[5][6]. Clocking pulse's characteristic depends on current sinking. There is a load capacitor connected from output to ground. Equation of capacitance and current is defined and this will determine delay of pulse[5]. Temperature compensation responsible will be full taken by temperature compensated current source.

Besides that, oscillation can be done using parasitic capacitance characteristic in MOSFET. SiC MOSFET is used to generate switching oscillation. SiC MOSFET able to operate at high temperature and frequency. It depends on the material characteristic of SiC MOSFET that will determine the parasitic capacitance. From this characteristic, circuit can be developed to generate oscillation. The characteristic of the MOSFET can be modelled out and equation will generate to control the oscillation. Hence, inductive load will connect to MOSFET to control resonant frequency according to the equation[8].

Using digital building block is another way to create oscillation. This include comparator, S-R latch and buffer. The operation is based on principle of relaxation oscillation. The temperature compensation is done by integrated feedback error (IEF). IEF composite of resistor and Op-Amp in which resistor is sensitive to temperature and Op-Amp will change output based on voltage across the resistor. The output voltage of Op-Amp will control MOSFET's gate voltage and hence current from will according to output voltage of Op-Amp. With that, current source will change according temperature to compensate temperature effect on current supply[1].

Last but not least, differential amplifier can generate oscillation. This can be done by feedback output to input through inverter[13]. The inverters are connected both side of the inputs to turn off and on the output state. This means that one side of output is turned off then the other side of output is turned on. By continue changing the state of outputs in opposite way, then square wave can be generated. The frequency can be controlled by adjusting the width and length channel of the MOSFETs in inverter[13].

2.4 Chapter Summary

Oscillation can be generated in different way. Commonly, oscillation circuit is using feedback from output to input through inverter or RC. Temperature compensated current source is provided to oscillator. Temperature compensation function majority depends on the current reference with temperature compensated. Fundamentally, temperature compensation technique start up from bandgap reference and zero temperature coefficient biasing. Bandgap reference can be done either PTAT or CTAT or both of them. Zero temperature coefficient biasing must defined their operation voltage in MOSFET within temperature range.

Chapter 3

METHODOLOGY

3.1 Introduction

In pervious chapter, temperature compensation current reference techniques and oscillation method developed by researchers have been studied. Each temperature compensated current reference and oscillator designs have their pros and cons. After review the temperature compensation technique, new temperature compensation oscillator circuit is developed. The circuit is combination from temperature compensation current reference circuit with oscillator circuit.

Basically, the temperature compensation oscillator circuit consists of two main parts. First part is compensated temperature current reference and second part is oscillation generator. Then, combine these two parts together to develop temperature compensated oscillator.

3.2 Project Development

At initial stage, implementation of temperature compensation current reference using circuit. PTAT current circuit is designed and calculation is done to determine the parameters need to be used in circuit. Then, CTAT current circuit is designed and calculation is done also to decide parameters in the circuit. Then combine PTAT and CTAT current circuit to cancel each other temperature effect. So, temperature compensated current source is develop[7]. The developed current reference will be used in oscillator.

The oscillator will use differential amplifier then feedback output to input through inverter. The design of oscillator starts from differential amplifier then inverter. The inverter will connect to differential amplifier to create astable pulse[13].

In the project, MOSFET model is using BSIM4 with 50nm and LTspice software to run simulation. Figure 3.1 shows the flow chart of developing temperature compensation current reference to indicate steps of working flow involved.

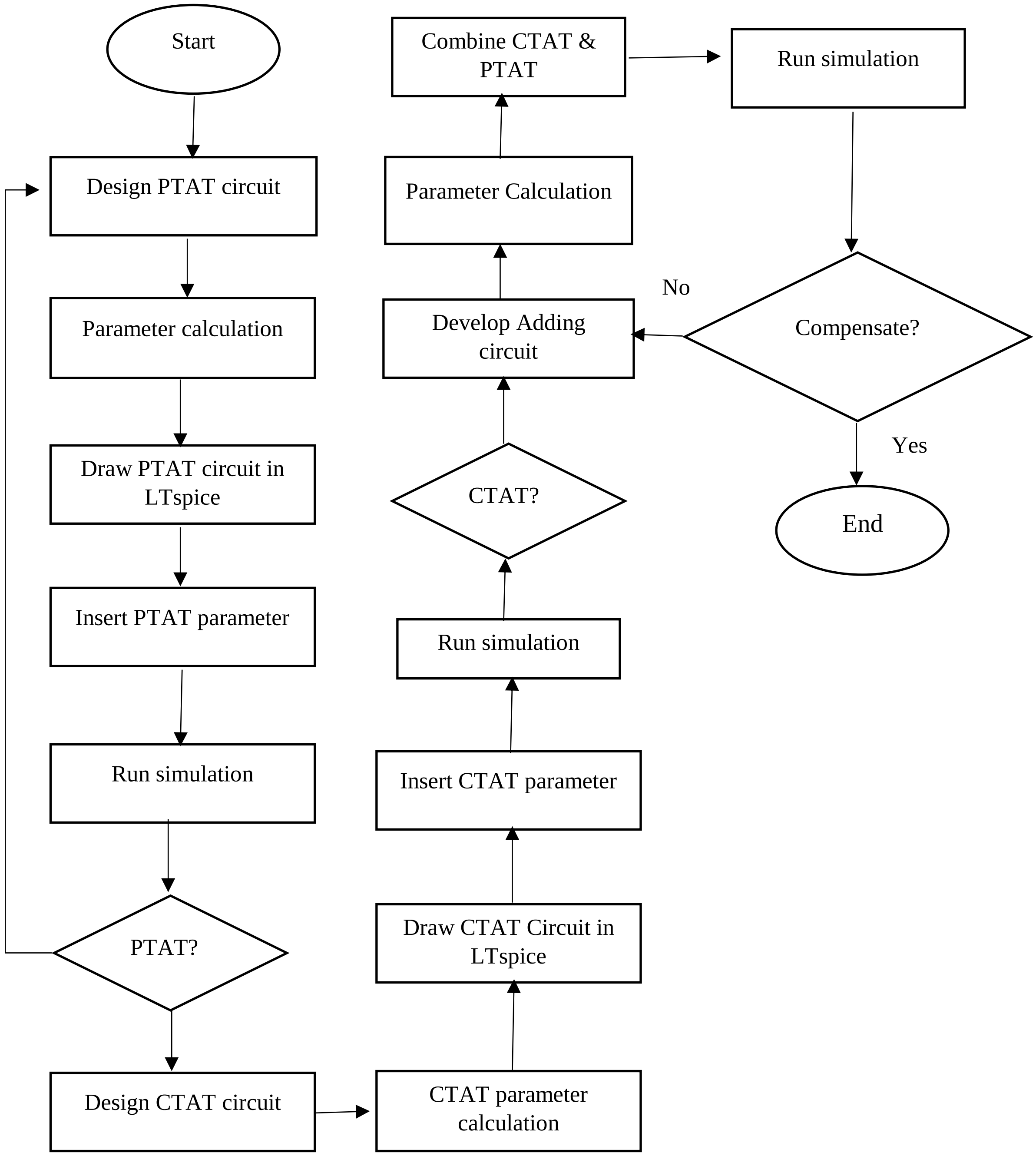

Figure 3.1: Flow chart of developing temperature compensation current reference

Working steps start with designing PTAT current circuit and calculate the parameters of PTAT current circuit as shown in Figure 3.1. Then, draw the circuit in LTspice and insert parameters that calculated. Run the simulation to determine the output of PTAT current circuit. If output of PTAT current circuit does not satisfy, the circuit will design again. If output is satisfied, then continue with designing CTAT current circuit and calculates the parameter of CTAT current circuit. The following steps are same as PTAT current circuit. After complete CTAT current circuit, adding current circuit is designed to combine PTAT and CTAT. Run the simulation in LTspice and determine the output of the current reference along temperature from -27℃ to 80℃. If output does not satisfy, adding current circuit will redevelop again. If output is satisfied, then temperature compensated current reference is completed.

Next, temperature compensated oscillator is developed by using differential amplifier. Then, differential amplifier will feedback output to input through inverter. The differential amplifier will use the current reference as its current source. Figure 3.2 shows the flow chart of development of temperature compensated oscillator.

Oscillator part starts with designing differential amplifier as shown in Figure 3.2. Then, differential amplifier design will be drawn using LTspice. The temperature compensated current source clamped to tail current of the differential amplifier as current reference. Parameter of differential amplifier is calculated and inserted to LTspice. Run simulation to determine differential amplifier weather it is in saturation mode. If result is not satisfied, parameters calculation will redo. If result is satisfied, inverter will be designed. The parameters of inverter is calculated and inserted to LTspice. Run simulation to determine efficiency of inversion of pulse. If result is satisfied, then the inverter will combine with differential amplifier. Then, simulation is done again by LTspice. If it able to generate 27MHz astable pulse along -27℃ to 80℃, the circuit is successful. If the circuit is not achieve the objective, then calculation is redo and modify the parameters.

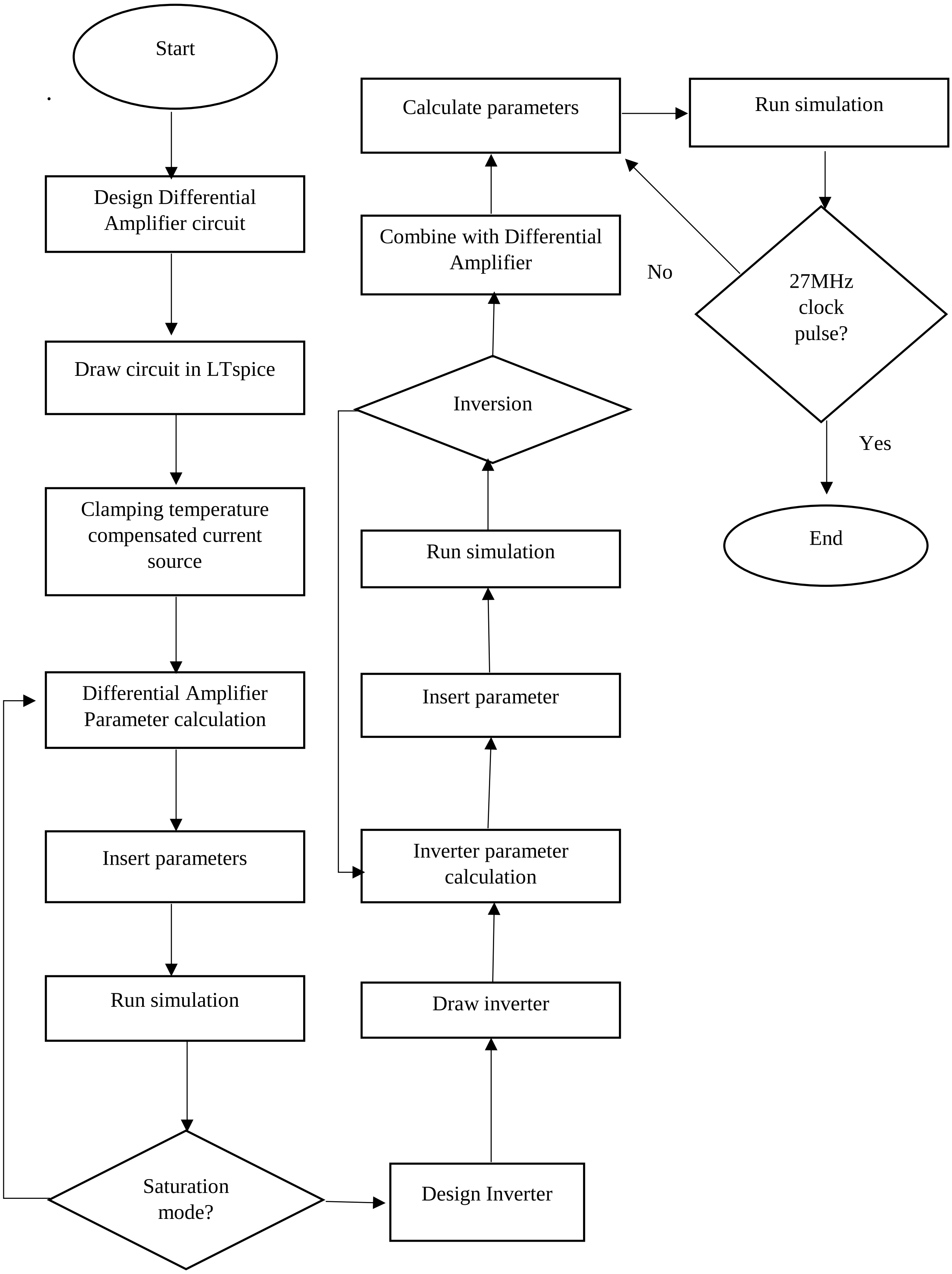

Figure 3.2: flow chart of development of temperature compensated oscillator

3.3 Circuit Implementation

In this section, circuit implementation of temperature compensation oscillator of 27MHz along -27℃ to 80℃ will be develop. The circuit implementation will do in step by step according project flow that decided in previous section. The ways of implementation will be shown in next section.

The section 3.3.1 and 3.3.2 will show implementation of CTAT and PTAT current circuit respectively. Then, section 3.3.3 will show implementation temperature compensated current source circuit. Next, section 3.3.4 will show develop oscillator circuit. Then, section 3.3.5 will show complete implementation of temperature compensated oscillator circuit. The circuit in each section will be drawn and done simulation using LTspice.

The whole circuit is fully using MOSFET model of 50nm BSIM 4. The parameters of 50nm BSIM 4 MOSFET model is shown on Table 3.1[14].

Table 3.1: Parameters of 50nm MOSFET with BSIM 4 model

Parameter	**Value**
Threshold voltage, Vth	0.22V(nmos) or -0.22V(pmos)
PMOS charge carrier mobility, μ_p	0.0095
NMOS charge carrier mobility, μ_n	0.032
Oxide capacitance per area, Cox	27 fF/um^2

3.3.1 PTAT current circuit

In developing PTAT current circuit, technique that proposed by [7] is referred. Figure 3.3 is shown circuit of PTAT current source circuit.

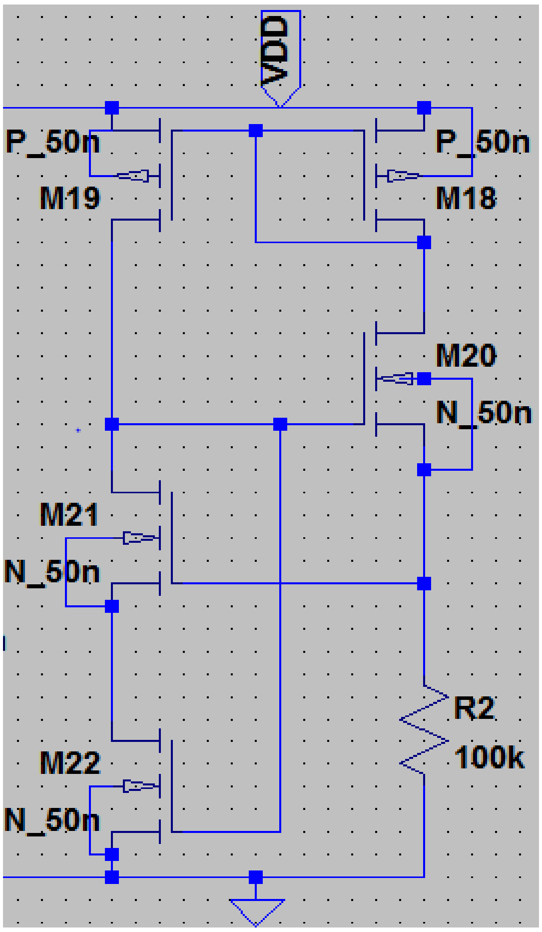

Figure 3.3: PTAT current source circuit

M22 is operated in triode region, it acts as resistor in this circuit. Drain current of M22, I_D is given by

$$I_{D(M22)} = \mu_n C_{OX} \frac{W}{L}\left[\left(V_{GS(M22)} - V_{th(M22)}\right)V_{DS(M22)} - \frac{1}{2}{V_{DS(M22)}}^2\right] \qquad (3.1)$$

Since M22 in triode region, $V_{DS(M22)}$ is very small then $I_{D(M22)}$ is reduced to equation given by

$$I_{D(M22)} = \mu_n C_{OX} \frac{W}{L}\left[\left(V_{GS(M22)} - V_{th(M22)}\right)V_{DS(M22)}\right] \qquad (3.2)$$

From equation (3.2), resistance equivalent, R equation can be obtained and is given by

$$R = \frac{V_{DS(M22)}}{I_{D(M22)}} = \frac{V_{DS(M22)}}{\mu_n C_{OX}\frac{W}{L}[(V_{GS(M22)} - V_{th(M22)})V_{DS(M22)}]}$$

$$R = \frac{V_{DS(M22)}}{I_{D(M22)}} = \frac{1}{\mu_n C_{OX}\frac{W}{L}[(V_{GS(M22)} - V_{th(M22)})]}$$

$$R = \frac{V_{DS(M22)}}{I_{D(M22)}} = \frac{1}{\mu_n C_{OX}\frac{W}{L}[(2V_{th(M22)} - V_{th(M22)})]}$$

$$R = \frac{V_{DS(M22)}}{I_{D(M22)}} = \frac{1}{\mu_n C_{OX}\frac{W}{L}[(V_{th(M22)})]} \quad (3.3)$$

Since $V_{GS(M22)}$ must larger than or equal $V_{th(M22)}$ plus $V_{th(M21)}$ ($V_{GS(M22)} \geq V_{th(M22)} + V_{th(M21)}$) and $V_{th(M22)} = V_{th(M21)}$, thus minimum value of $V_{GS(M22)}$ is $2V_{th}$, thus equation (3.3) can be obtained. Threshold voltage will decrease as temperature increase. Thus, equation (3.3) shows that R will increase as temperature increase. Besides that, current flow through resistor R2, I_{R2} is given by

$$I_{R2} = \frac{v_{GS(M22)} - v_{GS(M20)}}{R_2} \quad (3.4)$$

From equation (3.3), R will increase as temperature increases because V_{th} will decrease. Based on potential divider, $V_{GS(M22)}$ will increase as R increases. Hence in equation (3.4), current flow through resistor R2, I_{R2} will increase as temperature increases. Thus, the circuit in Figure 3.3 able to generate current source proportional to absolute temperature (PTAT) or positive temperature coefficient. So, by proper adjusting ratio of width to length of MOSFET, W/L, PTAT circuit can be achieved.

3.3.2 CTAT current circuit

In developing CTAT current circuit, technique that proposed by [7] is referred. Figure 3.4 shows CTAT current source circuit.

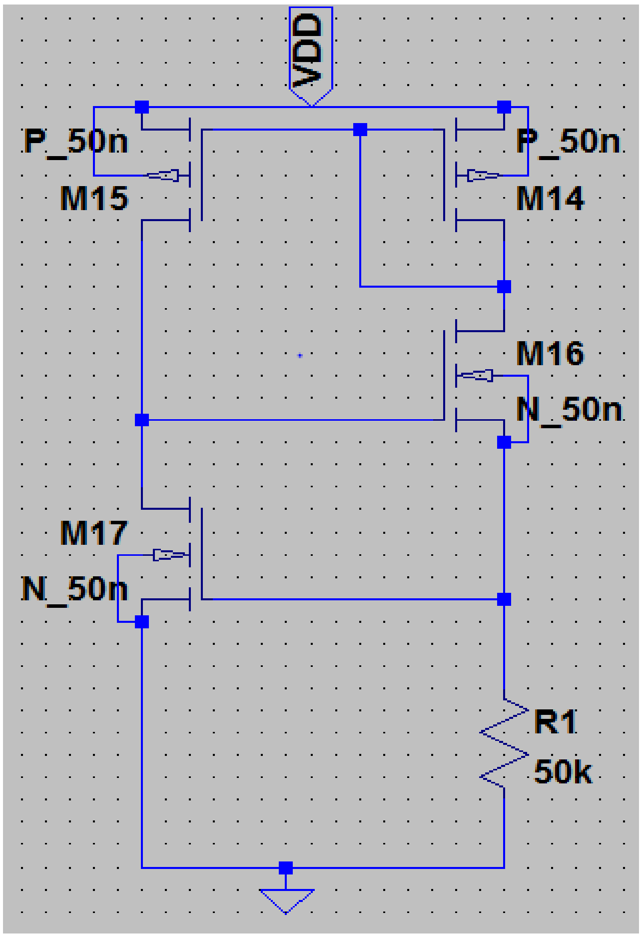

Figure 3.4: CTAT current source circuit

All MOSFETs are in saturation mode. The current flow through M17, $I_{D(M17)}$ is given by

$$I_{D(M17)} = \frac{1}{2}\mu_n C_{OX}\frac{W}{L}(V_{GS(M17)} - V_{th})^2 \tag{3.5}$$

From the equation (3.5), the gate voltage of M17, $V_{GS(17)}$ is given by

$$V_{GS(M17)} = V_{th} + \sqrt{\frac{2I_{D(M17)}}{\mu_n C_{OX}\frac{W}{L}}} \tag{3.6}$$

The current flow through resistor R1, I_{R1} is given by

$$I_{R1} = \frac{V_{GS(M17)}}{R_1} = \frac{V_{th} + \sqrt{\frac{2I_{D(M17)}}{\mu_n C_{OX}\frac{W}{L}}}}{R_1} \quad (3.7)$$

From equation (3.7), ratio of width to length, W/L can be adjusted and reduce I_{R1} to be approximately given by

$$I_{R1} \approx \frac{V_{th}}{R_1} \quad (3.8)$$

In order to realize equation (3.8), W/L must be significantly larger to cancel out second term in equation (3.7). From equation (3.8), it clearly shows that I_{R1} depends on V_{th} which is temperature dependant. So, when temperature increases, threshold voltage will decrease, hence I_{R1} will decrease. From there, complementary to absolute temperature (CTAT) current source circuit is developed. It able to give negative temperature coefficient. So, by proper adjusting ratio of width to length of MOSFET, W/L, CTAT circuit can be achieved.

3.3.3 Temperature compensated current source circuit

For developing temperature compensated current source, CTAT and PTAT current source circuit are combined. Combining CTAT and PTAT circuits is to cancel out each other temperature effect because negative temperature coefficient added to positive temperature coefficient gives zero temperature coefficient. In temperature compensated current source, one stage CTAT current source circuit and one stage PTAT current source are added together. Then, current mirror method is used to achieve combination circuit for CTAT and PTAT current source circuit. Figure 3.5 shows temperature compensated current source circuit.

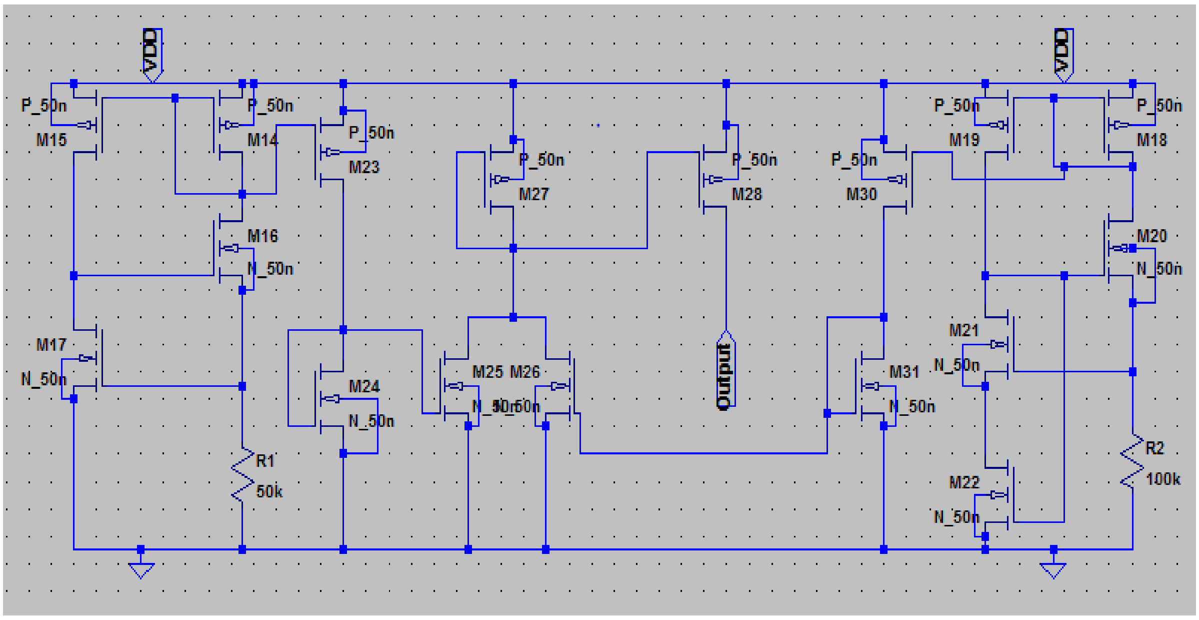

Figure 3.5: Temperature compensated current source circuit

CTAT current source is clamped to M23 and PTAT current source is clamped to M30. Then, current mirror technique used again to combine both current effect. Finally, the compensated current source clamped to M28 as output current source that will be clamped to tail current of oscillator.

The output current source value is calculated based on the requirement of the differential amplifier. Since output current source is clamped to tail current of differential amplifier, the value of output current source is derived by analysing the transconductance and gain of differential amplifier. The differential amplifier is using active loads, so the resistance of active loads, R_D is given by

$$R_D = \frac{V_{DS}}{I_{DS}} \tag{3.9}$$

V_{DS} in equation (3.9) is given by

$$V_{DS} = V_{DD} - V_S \tag{3.10}$$

Since active loads is using PMOS, the output of differential amplifier at common mode to get symmetrical swing pulse should be 0.5V and V_{DD} is voltage supply Thus, V_S is 0.5 V and V_{DD} is 1 V. Then, the equation (3.9) is reduced and given by

$$R_D = \frac{1-0.5}{I_{DS}} = \frac{0.5}{I_{DS}} \tag{3.11}$$

The differential amplifier should be proper biasing. So, the tail current and output current source is clamped in optimum mode if channel effect is eliminated. Assume the differential amplifier is in saturation mode and channel effect is eliminated. The output current must equal to tail current. The transconductance of differential amplifier is calculated to find out the value of output current and transcondcutance is given by

$$G_m = \sqrt{\frac{\mu_n C_{OX} W I_{ss}}{L}} \tag{3.12}$$

Where Gm is transconductance and Iss is tail current of differential amplifier.

The gain of amplifier, A is given by

$$A = \frac{V_{out}}{V_{in}} = G_m R_D = \sqrt{\frac{\mu_n C_{OX} W I_{ss}}{L}} R_D = \sqrt{\frac{\mu_n C_{OX} W I_{ss}}{L}} \frac{0.5}{I_{DS}} \tag{3.13}$$

Since I_{SS}=2I_{DS} to apply common mode in differential amplifier, equation (3.13) is reduced and given by

$$A = \sqrt{\frac{\mu_n C_{OX} W}{L I_{ss}}} \tag{3.14}$$

From equation (3.15), tail current Iss is given by

$$I_{ss} = \frac{\frac{\mu_n C_{OX} W}{L}}{A^2} \tag{3.15}$$

To get an sensitive input and output change, gain plays input role, gain, A, is given by

$$A = \frac{\Delta V_{out}}{\Delta V_{in}} \tag{3.16}$$

From equation (3.16), gain is ratio of output voltage changes to input voltage changes. The input voltage changes must be small and reasonable. Since threshold voltages of MOSFET is 0.22V, the input voltage change value will give effective influences to turn on and off mode. In this project, 5mV input voltages changes will give 0.4 V output voltage changes. From equation (3.16), the gain is given by

$$A = \frac{0.4\ V}{5mV} = 80 \tag{3.17}$$

From equation (3.17), gain is 80 and substitute to equation (3.15). The W/L value in equation (3.15) is defined by using LTspice. It done by trial and error method to find out W/L value will give saturation mode and found out that W/L is 60. Then equation (3.15) is reduced and given by

$$I_{ss} = \frac{\frac{\mu_n C_{OX} W}{L}}{A^2} = \frac{0.032 * 25 * 10^{-15} * 60}{80^2 * 10^{-12}} = 7.5\mu A \tag{3.18}$$

From equation (3.18), the tail current, Iss is 7.5 µA and is must same to output of compensated current source. So, the output of compensated current source , I_{out} is 7.5 µA.

3.3.4 Oscillation generator circuit

Differential amplifier is used to generate oscillation. The oscillator must able to generate 27MHz square wave. The differential amplifier must in saturation mode and well biasing. Inverter is used to control the inputs of differential amplifier. It used to turn on and off the inputs of the differential amplifier. When one input of differential amplifier is in saturation mode, then another input will turn off. By continue turning on and off in opposite way of the inputs, astable waves can be generated. Inverters connect both side of output of the differential amplifier, then feedback to the inputs of differential amplifier in opposite direction. Tail current of amplifier is generated by clamping temperature compensated current source. Figure 3.6 shows oscillator circuit. Parasitic capacitance in inverter determine the square wave shape and frequency. Parasitic capacitance of MOSFET is given by

$$C = C_{OX}WL \tag{3.19}$$

So, the total capacitance of inverter, C_{total} is given by

$$C_{total} = C_{OX}(W_N L_N + W_P L_P) \tag{3.20}$$

where C_{OX} is capacitance per unit area, W_N is width of NMOS, W_P is width of PMOS, L_P is length of PMOS and L_N is length of NMOS.

By adjusting length and width of MOSFETs in inverter, 27MHz square wave can be generated. Besides that, adding multistage inverter to achieve desired wave shape and frequency as well. So, in order to achieve targeted oscillation, adjusting width and length of MOSFETs and adding multistage inverter will be done. Then, temperature compensated current source is clamped into tail current of the differential amplifier. Thus, temperature compensated current source in charge temperature compensation for whole circuit.