Power Management Integrated Circuits
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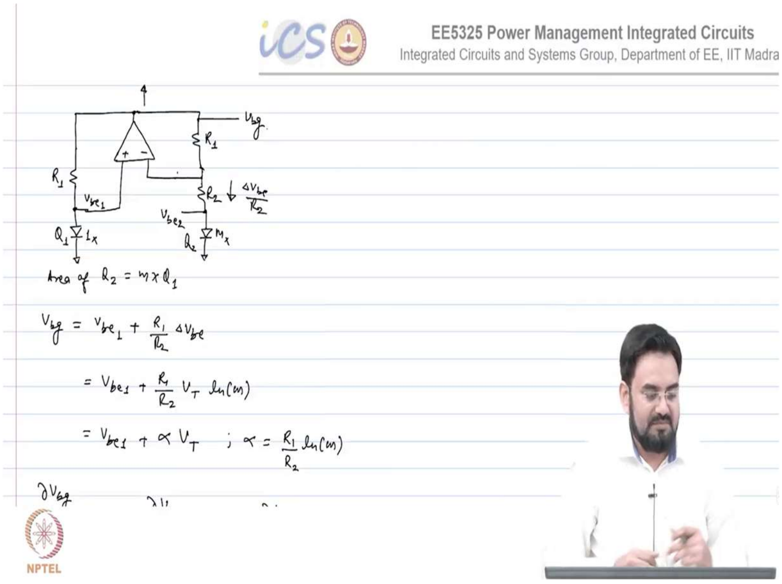
Lecture - 09
Bandgap Voltage Reference Circuit, Brokaw Bandgap Circuit

<u>Bandgap Voltage Reference:</u> The circuit diagram is shown in below figure.

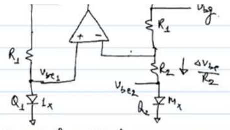


We need to generate the current in the resistor R_2 to be $\frac{\Delta V_{be}}{R_2}$. Which means the voltage at the other end of R_2 should be V_{be1} . We can't directly short the V_{be1} of Q1 to this.

To get this voltage as V_{be1} , we use negative Feedback. So, you just had an op-amp and with the virtual short property you will get the two voltages same. In order to find the negative feedback or find the sign of op-amp, apply a test signal at the output and move around the feedback and see what feedback is doing; whether it is moving your output signal in the same direction or in opposite. If it is a negative feedback, then it will try to oppose the variation in the output signal.

So, your output voltage $V_{bg} = V_{be1} + \frac{R_1}{R_2} \ \Delta V_{be}$

And we know the condition for bandgap is $\frac{\partial V_{bg}}{\partial T} = 0$. Now, follow the steps shown in below figures.



Area of $Q_2 = m \times Q_1$

$$V_{bg} = V_{be_1} + \frac{R_1}{R_2}\Delta V_{be}$$

$$= V_{be_1} + \frac{R_1}{R_2} V_T \ln(m)$$

$$= V_{be_1} + \alpha V_T \quad ; \alpha = \frac{R_1}{R_2}\ln(m)$$

$$\frac{\partial V_{bg}}{\partial T} = 0 \Rightarrow \frac{\partial V_{be_1}}{\partial V_T} = -\alpha \frac{\partial V_T}{\partial T} = -\alpha(86\,\mu V/K)$$

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$$\frac{\partial V_{be}}{\partial T} = -1.5\,mV$$

$$\alpha = 17.437$$

$$\frac{R_1}{R_2} \times \ln(m) = 17.437$$

$$m = 10$$

$$\frac{R_1}{R_2} = \frac{17.437}{\ln(m)} = 7.5$$

$R_2 = 100\,k\Omega$

$R_1 = 750\,k\Omega$

V_{bg} at room temp.

$$V_{bg} = V_{be} + \alpha V_T = 0.7V + 0.453 \quad (V_T = 26\,mV)$$

$$\simeq 1.15V$$

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Now choose $\frac{\partial V_{be}}{\partial T} = -2\,mV/K$

$$\alpha = \frac{2\,mV}{86\,\mu V} \simeq 23$$

$$V_{bg} = V_{be} + 23 \times V_T$$

$$= 0.7 + 0.598 \simeq 1.3V$$

$$\boxed{V_{bg} = 1.15V \text{ to } 1.3V \text{ for } \frac{\partial V_{be}}{\partial T} = -1.5\,mV/K \text{ to } -2\,mV/K}$$

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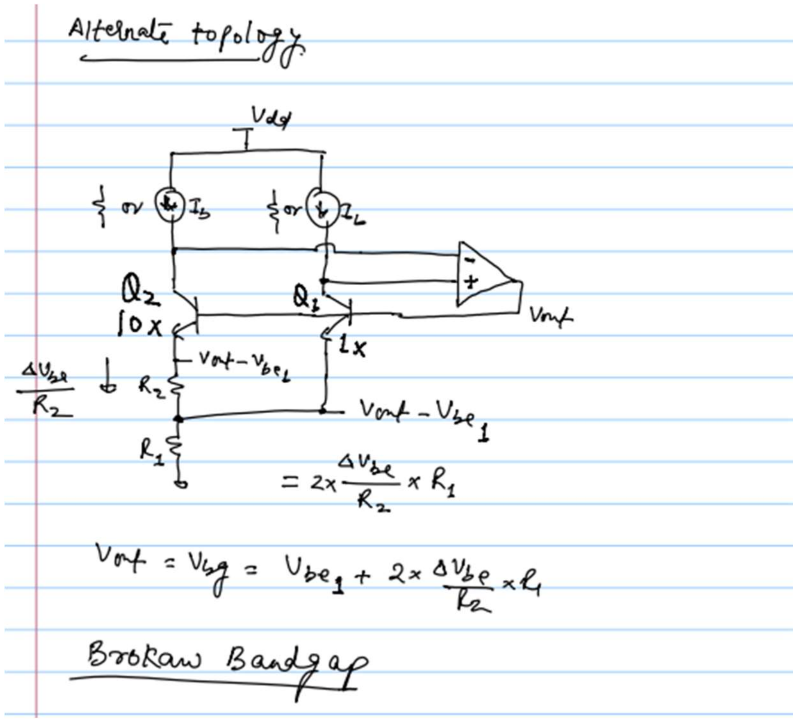
So, your V_{bg} = 1.15 to 1.3 V for $\frac{\partial V_{be}}{\partial T}$ = -1.5 to -2 $^{mV}/_{\circ K}$. And depending on the process you may hit any number in between these. And most of the time you get 1.2 V or 1.25 V. At room temperature band gap energy of silicon is 1.12 eV and at room temperature you are getting 1.15 V which is very close to your band gap energy of silicon. That's why we call it bandgap reference.

The zest of the bandgap is, you need PTAT and CTAT. And CTAT is mostly build using V_{be}. So, you just use 0.7 V there and then you scale the V_T or ΔV_{be} by simply connecting a resistor and flowing $\frac{\Delta V_{be}}{R}$ current into that. In this way you can scale that number and you can match the slope of your V_{be} and ΔV_{be} and cancel the temperature dependence.

This was just one topology and you can build numerous topologies as long as you know how to build a CTAT and a PTAT. All you need to just add the two after scaling them and you can build like 10s of topologies of bandgap. That's why if you just Google, you will find numerous topologies of bandgap. It is not important like how you build it; the most important thing is to get a most accurate reference voltage. You can do it without op-amp also, but it will have a little bit more inaccuracy compared to op-amp because op-amp has a negative feedback.

So, it ensures that Q_1 and Q_2 have the same current. But if you do not have an op-amp, then those currents may not match and you will get some non-linearity behaviour in the output and that will introduce inaccuracy in the output. If you are not concerned about very accurate bandgap then you can do without op-amp and you can save the current as well as area in your bandgap circuit. So, it all depends what you require.

Brokaw Bandgap: The circuit diagram is shown in below figure.



In order to have $\Delta V_{be} = V_T \ln(m)$, you have to make sure that in both branches you have the same current; so that the m factor is only coming from your reverse saturation current.

So, 2x current is flowing into resistor R1. So, we get

$$V_{out} = V_{bg} = V_{be1} + 2\,\frac{R_1}{R_2}\;\Delta V_{be}$$

So, the only difference is if you choose Q2 as 10x then the value which required for ratio of $\frac{R_1}{R_2}$ will be half here, because you have a 2x factor. Otherwise rest of the things are same. this is Brokaw bandgap reference. This is named after the guy who implemented this. So, if you build any new topology you can name it after your name.