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Thermal Aware Power Efficient Frame Buffer Design on Kintex-7 FPGA

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***Abstract*— This paper presents thermal scaling techniques in order to design low power Frame Buffer. Kintex-7 FPGA is used to implement this design. It is observed at 100GHz device operating frequency, on scaling the temperature from 65˚C to -15˚C with 250 LFM, we are achieving 71.82% reduction for Leakage Power, 4.62% reduction for Total Power and 97.34% for junction temperature. Under same frequency and temperature scaling with LFM is taken as 500, Leakage power, Total Power and Junction power is reduced up to 56.25%, 4.35% and 99.387% respectively.**

Keywords—Thermal Aware, Frequency Scaling, FPGA, Frame Buffer, Low Power, Total Power, Ambient Temperature, Junction Temperature.

I. INTRODUCTION

A Frame Buffer is also said Frame Store is in fact a portion of RAM that contains a bitmap that is driven to a video display from a memory buffer that contains a complete frame of data. Color values are commonly stored in 1-bit binary, 4-bit palettized, 8-bit palettized, 16-bit high color and 24-bit true color format. Here in this paper we have designed a Frame Buffer in Kintex in 8-bit format so that our Frame Buffer allows 256 different colors.

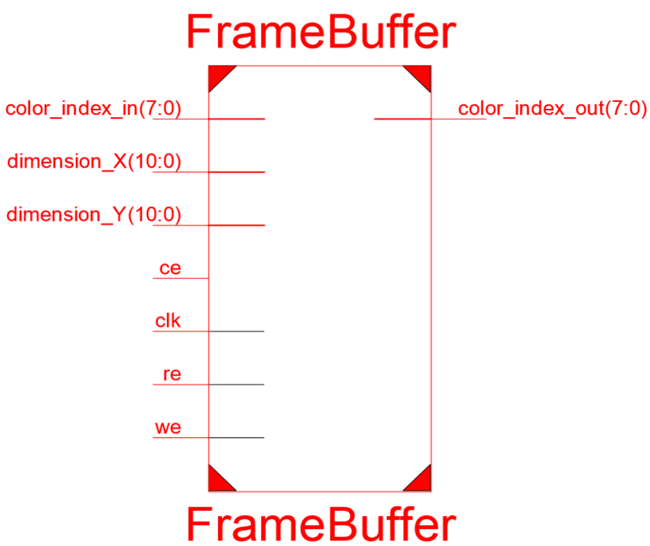

Figure 1: Top Level Schematic of Frame Buffer

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We scaled the ambient temperature as well as the frequency and found that there is a huge reduction in power consumption when we scale the frequency from 100GHz to 1GHz along with scaling the ambient temperature from 65℃ to -15℃. The results have been shown in detail in the result portion. There was an important observation during experiment according to which for 1THz frequency we found that the Junction Temperature was exceeding the absolute maximum temperature. Due to that we have ignored the difference came for 1THz frequency. Figure 1 shows the Top level schematic diagram for Frame Buffer. Color_index_in, dimension_X, dimension_Y, ce, clk, re and we are the inputs for the Frame Buffer while color_index_out is the output for the Frame Buffer.

II. LITERATURE REVIEW

According to [1] due to signals of RGB video is not properly filtered on PCB, that causes problems in video frame buffer design. The work in [1] tells the detail about important issues of EMI regarding graphics, connector's effect, local resonance and process of filtering. In [2], for various display equipments, limited power is available and need some procedure for frame buffers for efficiently shorten the power consumption of display systems. Hybrid architecture for frame buffer is used in mobile devices in order to condense the energy requirements of display subsystems in [4].The result in [4] shows that there is 43% reduction in energy requirements of newly designed frame buffer as compared to power DRAM frame buffer. In [6] warping module for a real time image is implemented in hardware, for that purpose reverse mapping with the use of look up table is applied to get the some relation of original image to warped image and for storing source image, frame buffer are used. In [7]Various process variation behavior is discussed based on leakage current and temperature.

III. OUTCOMES OF THERMAL SCALING

It is an important observation that we found no change in Clock Power, Logic Power, Signals Power and IOs Power due to thermal scaling. But there are effects of thermal scaling found on the Leakage Power, Total Power and Junction Temperature. So here in the result portion we have shown the effects. Specially in B part of the result we have shown the results found for two different Air Flow of the environment which are 250 LFM and 500 LFM.

A. *Clock Power, Logic Power, Signal Power and IOs Power Dissipation of Frame Buffer for any Temperature:*

Table 1: Clock Power, Logic Power & IOs Power for different frequency in almost any ambient temperature:

	1 GHz	10 GHz	100 GHz	1 THz
Clock Power	0.005	0.049	0.491	4.912
Logic Power	0.001	0.004	0.024	0.227
Signal Power	0.002	0.014	0.120	1.184
IOs Power	0.030	0.303	3.029	30.293

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It is found that while we do thermal scaling then for each of 65°C, 55°C, 45°C, 35°C, 25°C, 15°C, 5°C, -5°C and -15°C room temperature we observed 98.98% reduction in Clock Power, 95.83% reduction in Logic Power, 98.33% reduction in Signals Power and 99.00% reduction in IOs Power when we increased the frequency from 1GHz to 100GHz as shown in Table 1 and Figure 2. The variation in power is much more if we increase the frequency to 1THz. But if we do so we observed that Junction Temperature exceeds absolute maximum temperature. Thus we ignore that variation for 1THz.

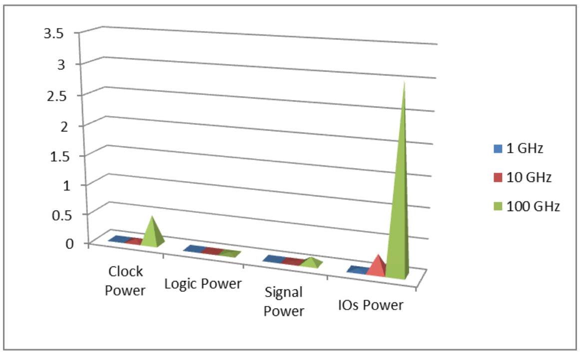

Figure 2: Clock Power, Logic Power, Signal Power & IOs Power for different frequencies at all ambient temperature we have measured.

B. Temperature scaling to see the variance in Leakage Power, Total Power & Junction Temperature for different frequencies.

1. Leakage Power, Total Power & Junction Temperature when Room Temperature is 65°C:

Table 2: Leakage Power, Total Power & Junction Temperature for different frequency at 65° ambient temperature:

		1 GHz	10 GHz	100 GHz	1 THz
Air Flow 250 LFM	Leakage Power	0.161	0.167	0.252	0.813
	Total Power	0.198	0.537	3.917	37.428
	Junction Temp	65.9	67.5	83.0	125
Air Flow 500 LFM	Leakage Power	0.160	0.166	0.240	0.813
	Total Power	.198	0.536	3.905	37.428
	Junction Temp	65.9	67.2	81.2	125

At 250 LFM Air Flow when we change the frequency from 1GHz to 100GHz at a fixed ambient temperature of 65°C we found 36.11% increment in Leakage Power, 94.94% increment in Total Power and 20.60% increment in Junction Temperature. When we changed the Air Flow to 500 LFM we found 33.33% increment in Leakage Power, 94.92% increment in Total Power and 18.84% increment in Junction

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Temperature for our Frame Buffer as shown in Table 2 and Figure 3. Due to the observation of Junction Temperature exceeding absolute maximum temperature results found in 1THz frequency is ignored.

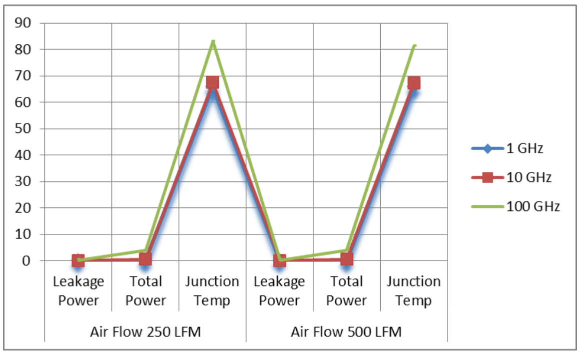

Figure 3: Leakage Power, Total Power & Junction Temperature for different frequency at 65˚ ambient temperature.

2. Leakage Power, Total Power & Junction Temperature when Room Temperature is 55˚C:

Table 3: Leakage Power, Total Power & Junction Temperature for different frequency at 55˚ ambient temperature:

		1 GHz	10 GHz	100 GHz	1 THz
Air Flow 250 LFM	Leakage Power	0.128	0.132	0.191	0.813
	Total Power	0.165	0.502	3.856	37.428
	Junction Temp	55.8	57.3	72.7	125
Air Flow 500 LFM	Leakage Power	0.127	0.131	0.182	0.813
	Total Power	0.165	0.501	3.847	37.428
	Junction Temp	55.7	57.1	71.0	125

At 250 LFM Air Flow when we change the frequency from 1GHz to 100GHz at a fixed ambient temperature of 55˚C we found 32.98% increment in Leakage Power, 95.71% increment in Total Power and 23.24% increment in Junction Temperature. When we changed the Air Flow to 500 LFM we found 30.21% increment in Leakage Power, 95.71% increment in Total Power and 21.54% increment in Junction Temperature for our Frame Buffer as shown in Table 3 and Figure 4. Due to the observation of Junction Temperature exceeding absolute maximum temperature results found in 1THz frequency is ignored.

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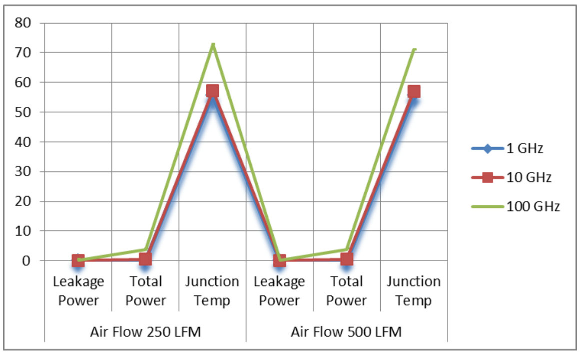

Figure 4: Leakage Power, Total Power & Junction Temperature for different frequency at 55˚ ambient temperature.

3. Leakage Power, Total Power & Junction Temperature when Room Temperature is 45˚C:

Table 4: Leakage Power, Total Power & Junction Temperature for different frequency at 45˚ ambient temperature:

		1 GHz	10 GHz	100 GHz	1 THz
Air Flow 250 LFM	Leakage Power	0.106	0.109	0.148	0.813
	Total Power	0.143	0.479	3.813	37.428
	Junction Temp	45.7	47.2	62.5	125
Air Flow 500 LFM	Leakage Power	0.106	0.108	0.142	0.813
	Total Power	0.143	0.478	3.808	37.428
	Junction Temp	45.6	47.0	60.8	125

Again at 250 LFM Air Flow when we change the frequency from 1GHz to 100GHz at a fixed ambient temperature of 45˚C we found 28.37% increment in Leakage Power, 96.24% increment in Total Power and 26.88% increment in Junction Temperature. When we changed the Air Flow to 500 LFM we found 25.35% increment in Leakage Power, 96.24% increment in Total Power and 25.00% increment in Junction Temperature for our Frame Buffer as shown in Table 4 and Figure 5. Due to the observation of Junction Temperature exceeding absolute maximum temperature results found in 1THz frequency is ignored.

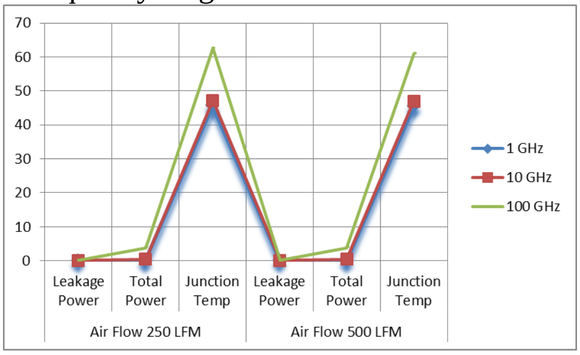

Figure 5: Leakage Power, Total Power & Junction Temperature for different frequency at 45˚ ambient temperature.

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4. Leakage Power, Total Power & Junction Temperature when Room Temperature is 35˚C:

Table 5: Leakage Power, Total Power & Junction Temperature for different frequency at 35˚ ambient temperature:

		1 GHz	10 GHz	100 GHz	1 THz
Air Flow 250 LFM	Leakage Power	0.091	0.093	0.119	0.813
	Total Power	0.129	0.463	3.785	37.428
	Junction Temp	35.6	37.1	52.4	125
Air Flow 500 LFM	Leakage Power	0.091	0.093	0.115	0.813
	Total Power	0.129	0.463	3.781	37.428
	Junction Temp	35.5	36.9	50.7	125

For 250 LFM Air Flow when we change the frequency from 1GHz to 100GHz at a fixed ambient temperature of 35˚C we found 23.52% increment in Leakage Power, 96.59% increment in Total Power and 32.06% increment in Junction Temperature. When we changed the Air Flow to 500 LFM we found 20.86% increment in Leakage Power, 96.58% increment in Total Power and 29.98% increment in Junction Temperature for our Frame Buffer as shown in Table 5 and Figure 6. Due to the observation of Junction Temperature exceeding absolute maximum temperature results found in 1THz frequency is ignored.

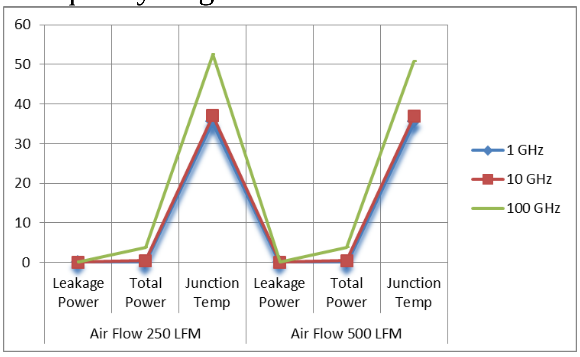

Figure 6: Leakage Power, Total Power & Junction Temperature for different frequency at 35˚ ambient temperature.

5. Leakage Power, Total Power & Junction Temperature when Room Temperature is 25˚C:

Table 6: Leakage Power, Total Power & Junction Temperature for different frequency at 25˚ ambient temperature:

		1 GHz	10 GHz	100 GHz	1 THz
Air Flow 250	Leakage Power	0.082	0.083	0.100	0.813
	Total Power	0.120	0.454	3.765	37.428

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LFM	Junction Temp	25.6	27.1	42.3	125
Air Flow 500 LFM	Leakage Power	0.082	0.083	0.098	0.813
	Total Power	0.120	0.453	3.763	37.428
	Junction Temp	25.5	26.9	40.6	125

For 250 LFM Air Flow when we change the frequency from 1GHz to 100GHz at a fixed ambient temperature of 25˚C we found 18.00% increment in Leakage Power, 96.81% increment in Total Power and 39.47% increment in Junction Temperature. When we changed the Air Flow to 500 LFM we found 16.32% increment in Leakage Power, 96.81% increment in Total Power and 37.19% increment in Junction Temperature for our Frame Buffer as shown in Table 6 and Figure 7. Due to the observation of Junction Temperature exceeding absolute maximum temperature results found in 1THz frequency is ignored.

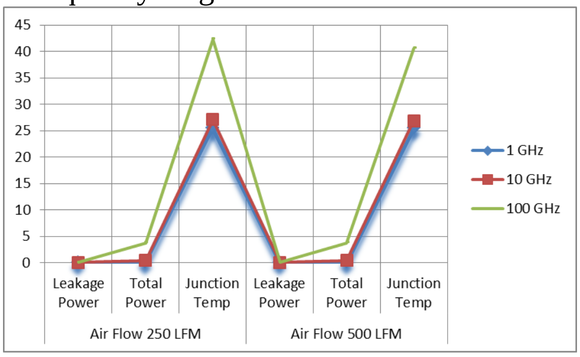

Figure 7: Leakage Power, Total Power & Junction Temperature for different frequency at 25˚ ambient temperature.

6. Leakage Power, Total Power & Junction Temperature when Room Temperature is 15˚C:

Table 7: Leakage Power, Total Power & Junction Temperature for different frequency at 15˚ ambient temperature:

		1 GHz	10 GHz	100 GHz	1 THz
Air Flow 250 LFM	Leakage Power	0.076	0.077	0.088	0.813
	Total Power	0.114	0.447	3.753	37.428
	Junction Temp	15.5	17.1	32.3	125
Air Flow 500 LFM	Leakage Power	0.076	0.077	0.086	0.813
	Total Power	0.114	0.447	3.752	37.428
	Junction Temp	15.5	16.9	30.6	125

For 250 LFM Air Flow when we change the frequency from 1GHz to 100GHz at a fixed ambient temperature of 15˚C we found 13.63% increment in Leakage Power, 96.96% increment in Total Power and 52.01% increment in Junction Temperature.

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When we changed the Air Flow to 500 LFM we found 11.62% increment in Leakage Power, 96.96% increment in Total Power and 49.34% increment in Junction Temperature for our Frame Buffer as shown in Table 7 and Figure 8. Due to the observation of Junction Temperature exceeding absolute maximum temperature results found in 1THz frequency is ignored.

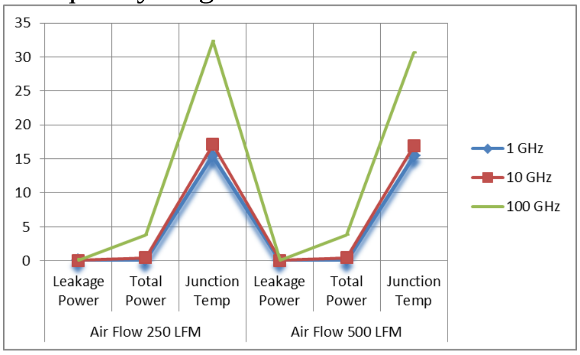

Figure 8: Leakage Power, Total Power & Junction Temperature for different frequency at 15˚ ambient temperature.

7. Leakage Power, Total Power & Junction Temperature when Room Temperature is 5˚C:

Table 8: Leakage Power, Total Power & Junction Temperature for different frequency at 5˚ ambient temperature:

		1 GHz	10 GHz	100 GHz	1 THz
Air Flow 250 LFM	Leakage Power	0.072	0.072	0.080	0.813
	Total Power	0.109	0.443	3.745	37.428
	Junction Temp	5.5	7.0	22.2	125
Air Flow 500 LFM	Leakage Power	0.072	0.072	0.079	0.813
	Total Power	0.109	0.442	3.744	37.428
	Junction Temp	5.5	6.8	20.5	125

For 250 LFM Air Flow when we change the frequency from 1GHz to 100GHz at a fixed ambient temperature of 5˚C we found 10.00% increment in Leakage Power, 97.08% increment in Total Power and 75.22% increment in Junction Temperature. When we changed the Air Flow to 500 LFM we found 8.86% increment in Leakage Power, 97.08% increment in Total Power and 73.17% increment in Junction Temperature for our Frame Buffer as shown in Table 8 and Figure 9. Due to the observation of Junction Temperature exceeding absolute maximum temperature results found in 1THz frequency is ignored.

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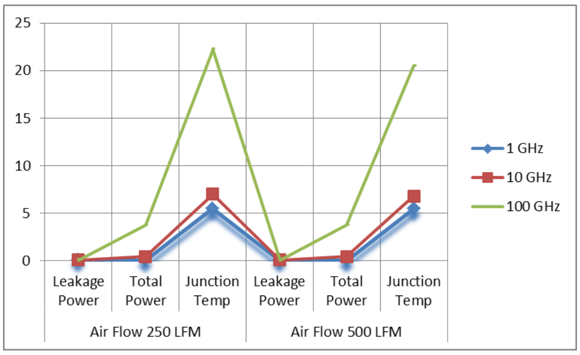

Figure 9: Leakage Power, Total Power & Junction Temperature for different frequency at 5˚ ambient temperature.

8. Leakage Power, Total Power & Junction Temperature when Room Temperature is -5˚C:

Table 9: Leakage Power, Total Power & Junction Temperature for different frequency at -5˚ ambient temperature:

		1 GHz	10 GHz	100 GHz	1 THz
Air Flow 250 LFM	Leakage Power	0.068	0.069	0.075	0.813
	Total Power	0.106	0.439	3.740	37.428
	Junction Temp	-4.5	-3	12.2	125
Air Flow 500 LFM	Leakage Power	0.068	0.069	0.074	0.813
	Total Power	0.106	0.439	3.739	37.428
	Junction Temp	-4.6	-3.2	10.5	125

For 250 LFM Air Flow when we change the frequency from 1GHz to 100GHz at a fixed ambient temperature of -5˚C we found 9.33% increment in Leakage Power, 97.16% increment in Total Power and 136.88% increment in Junction Temperature. When we changed the Air Flow to 500 LFM we found 8.10% increment in Leakage Power, 97.16% increment in Total Power and 143.80% increment in Junction Temperature for our Frame Buffer as shown in Table 9. Due to the observation of Junction Temperature exceeding absolute maximum temperature results for 1THz frequency is ignored.

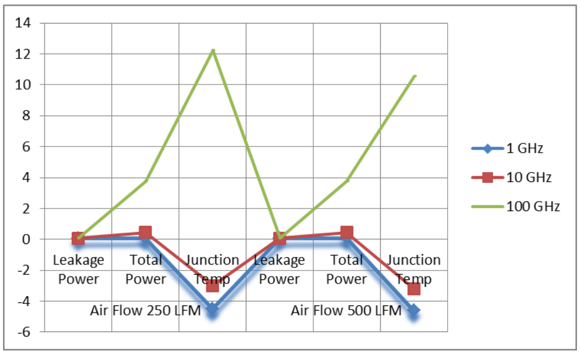

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Figure 10: Leakage Power, Total Power & Junction Temperature for different frequency at -5˚ ambient temperature.

9. Leakage Power, Total Power & Junction Temperature when Room Temperature is -15˚C:

Table 10: Leakage Power, Total Power & Junction Temperature for different frequency at -15˚ ambient temperature:

		1 GHz	10 GHz	100 GHz	1 THz
Air Flow 250 LFM	Leakage Power	0.066	0.066	0.071	0.813
	Total Power	0.104	0.437	3.736	37.428
	Junction Temp	-14.5	-13.0	2.2	125
Air Flow 500 LFM	Leakage Power	0.066	0.066	0.070	0.813
	Total Power	0.104	0.437	3.735	37.428
	Junction Temp	-14.6	-13.2	0.5	125

Finally for 250 LFM Air Flow when we change the frequency from 1GHz to 100GHz at a fixed ambient temperature of -15˚C we found 7.04% increment in Leakage Power, 97.21% increment in Total Power and 759.09% increment in Junction Temperature. When we changed the Air Flow to 500 LFM we found 5.71% increment in Leakage Power, 97.21% increment in Total Power and 3020.00% increment in Junction Temperature for our Frame Buffer as shown in Table 10 and Figure 10. Due to the observation of Junction Temperature exceeding absolute maximum temperature results found in 1THz frequency is ignored.

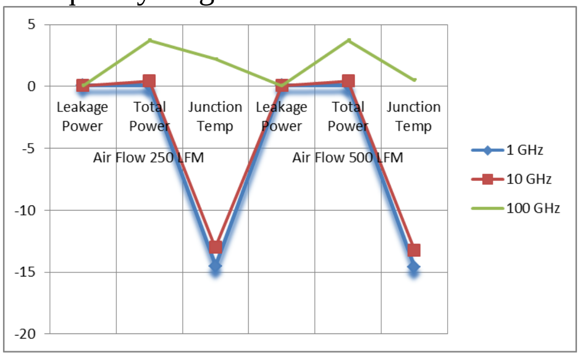

Figure 11: Leakage Power, Total Power & Junction Temperature for different frequency at -15˚ ambient temperature.

IV. CONCLUSION

Frequency scaling technique has a great impact on our Frame Buffer. Keeping the ambient temperature constant when we scaled frequency we found a great amount of reduction on Clock power, Logic power, Signals power as well as IOs power consumption which is up to 98.99%, 95.83%, 98.33% & 99.00% consecutively in cases, whereas the fluctuation in Leakage power, Total power and Junction temperature consumption is a little less. The mentioned reduction in Leakage power is up to 36.11%, Total power is up to 94.92% and Junction Temperature is 22%

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apparently for a 250 LMF Air flow when the frequency is scaled from 100GHz to 1GHZ. On the other hand when we deal with a 500 LMF Air flow we find a reduction of up to 34% in Leakage power, 95% in Total power and about 19% in Junction temperature for positive ambient temperature. It is also observed that if we deal with negative ambient temperature then we find nearly 97-98% reduction in Total power. On scaling the temperature from 65℃ to -15℃ with LFM 250 and device operating frequency is 100GHz, there is 71.82%, 4.62% and 97.34% reduction in Leakage power, total power and junction temperature respectively. Under same frequency and temperature scaling scheme with 500 LFM, leakage power is reduced up to 56.25%, total power is reduced up to 4.35% and junction temperature is reduced up to 99.38%.

V. FUTURE SCOPE

This Frame Buffer has been implemented in Kintex in this paper. In future the same Frame Buffer can be implemented in Airtex7 and Virtex. Here in this paper we have used Frequency and Thermal scaling technique. Capacitance scaling, Voltage scaling and IO scaling can be done to make it more efficient. Here in this paper we have designed a 8bit Frame Buffer to provide 256 different color schemes whereas in future there are scope to design 16-bit or more Frame Buffer.

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