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Citation for published version (APA):

DOI:
10.1109/ISSCC.2009.4977350

Document status and date:
Published: 01/01/2009

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:
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Download date: 28. Feb. 2019
8.1 An Ultra-Low-Energy/Frame Multi-Standard JPEG Co-Processor in 65nm CMOS with Sub/Near-Threshold Power Supply

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Many digital ICs can benefit from sub/near threshold operations that provide ultra-low-energy/operation for long battery lifetime. In addition, sub/near threshold operation largely mitigates the transient current hence lowering the ground bounce noise. This also helps to improve the performance of sensitive analog circuits on the chip, such as delay-loop loops (DLL), which is crucial for the functioning of large digital circuits. However, aggressive voltage scaling causes throughput and reliability degradation. This paper presents SubJPEG, a state-of-the-art multi-standard 65nm CMOS JPEG encoding co-processor that enables ultra-wide VDDH scaling. With a 0.45V power supply, it delivers 15fps 640×480 VGA application with only 1.3pJ/operation energy consumption per DCT and quantization computation. This co-processor is very suitable for applications such as digital cameras, portable wireless and medical imaging. To the best of our knowledge, this is the largest sub-threshold processor so far.

The architecture of SubJPEG is shown in Fig. 8.1.1. The design is fully compliant with the JPEG encoder baseline standard [1]. Asynchronous FIFOs (AFIFOs) are located at the front-end of the data-path to enable an flexible interface to standard bus interfaces such as PCI/PCI-X/PCI-Express. For each frame, the external main CPU issues a command to the configuration register file of the JPEG processor. The command includes the source data start address/length, destination data start address, YUV sampling ratio, programmable quantization table coefficients, etc. SubJPEG accommodates two command slots in the configuration register file so as to minimize the inter-frame configuration latency. The JPEG data-path has three main stages: (1) 2D-DCT transformation, (2) Quantization, and (3) Huffman encoding. A pair of DCT and Quantization modules is denoted as an "engine". SubJPEG has 4 engines capable of pulling up signals from sub-threshold VDDL to VDDH (~ VDDL+300mV). The 2nd stage level shifting is performed through feedback structured level-shifters from VDDL to 1.2V I/O pad.

The chip is fabricated in a 65nm 7-layer standard VDD CMOS process. A micrograph of the chip is shown in Fig. 8.1.7. The core area is 1.4×1.4mm^2 without pads. The chip accommodates two 640×480 VGA applications with 15fps each. Measurements of energy and speed performance are summarized in Fig. 8.1.6.

Acknowledgements:
The authors thank Leo Sevat and Maurice Meijer for the support during backend and test- ing of the chip.

References:
Figure 8.1.1: SubJPEG system block diagram.

Figure 8.1.2: Configurable Vt Balancer.

Figure 8.1.3: Improving sub-threshold drivability by exploiting Vt mismatch between parallel transistors.

Figure 8.1.4: Illustration of prohibited structures in sub-threshold library and 2-stage level shift scheme.

Figure 8.1.5: Waveforms from logic analyzer and Vt balancer measurements from oscilloscope.

Figure 8.1.6: (a) Energy/operation for each engine, (b) Throughput for 4 engines and possible real-time image applications.
Figure 8.1.7: Die micrograph and core layout of SubJPEG test chip in 65nm CMOS.