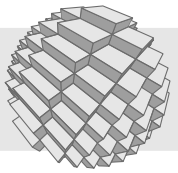


dombert SoC

MJPEG Streaming System on Chip

The *dombert* System on Chip (SoC) is a programmable JPEG encoder and streaming engine for FPGA based platforms, patent-free and independent of vendor specific IP.

It is part of the cCAP (configureable Custom Application Processor) family concept by section5.ch. Based on a resource and power saving open stack machine architecture, it provides high network throughput performance while aiming at minimum complexities for software programmers.

The compact instruction set of the core architecture enables very compact program code as well as customer specific micro code extensions with DSP emulation functionality.

1 Functional overview 'dombert'

- 32 Bit processor 'ZPUng' v1.1, three stage pipeline @50 Mhz
- Wishbone-Bus for address decoding and peripherals
- Autobuffer DMA for high speed data I/O
- Programmable in C (GCC)
- Hardware Debugger (JTAG), GDB
- Ethernet, high performance UDP/IP stack

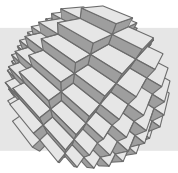
For technical specifications of the standard configuration, see Table 1.

Tab. 1: dombert standard configuration

Technical specifications		
Memory configuration		
ROM	256kB	Overlay program memory (SPI) read only
L1RAM	16kB	Level one program and data segment
L1CACHE	16kB	Program memory or ROM cache (configureable)
SRAM	2kB	Dedicated Stack Memory
SPAD	8kB	Two ScratchPad RAM buffers for peripheral data I/O
Peripherals		
SCACHE	1	SPI flash cache
SIC	1	System Interrupt Controller with six peripheral channels and four configureable priorities
DMAA	2	Autobuffer DMA for high speed RX/TX
UART	1	UART console
TWI	1	Two wire interface (I2C compatible)
MAC	1	Media Access Control Core (RGMII/MDIO), 100M/1G
VIDEO	1	Customized "Video Hub" for RGB/YUV format conversion
JPEG_L2	1	Low latency JPEG 'two lane' encoder for 720p60 video or custom formats

2 JPEG encoder

The JPEG encoder engine is able to process YUV video at pixel frequencies up to 100 MHz in the *dombert* configuration and stream them to a host system that understands a RFC2435 compliant MJPEG RTP stream. It can operate on a 100M link at lower resolutions, however for full error free high quality transmission, a 1G setup is required. See details in Table 2.



Tab. 2: jpeg_core 'dombert' configuration

Feature	Property
Input format	YUV422 or dual tap monochrome
Input width (max.)	2048 (configureable at synthesis)
Buffering	8 scanlines per channel
Streaming	Raw JPEG (MJPEG/RTP and JFIF compliant)
JFIF (JPEG file format) generation	Microcontroller interface (non-hardcoded)
Huffman tables	fixed, non-configureable
Failure/Error resilience (Restart Marker)	N/A

3 Video unit

The configureable video unit has the following functionality:

- Debayer pipeline
- Direct bayer to YUV422 conversion
- Video diagnostics (frame format detection)
- Routeable video signal test generator

4 Reference setup

The reference environment for the dombert SoC is based on a Linux gstreamer toolchain for low latency video streaming. Users can develop custom applications or image processing plugins based either on the gstreamer SDK or include gstreamer capabilities into own programs.

5 Simulation

The entire *dombert* SoC can be co-simulated in a virtual machine. Advantages:

- Cycle-accurate verification of correct functionality
- Efficient visual debugging in trace waveforms, optional on-chip trace debugging via Ethernet
- Co-Simulation with Python-Scripts for functional verification

6 Example applications

- Low latency Motion JPEG streaming over RTP/UDP (IP camera)
- Real-Time Network stress testing

7 Reference-Platforms

The dombert SoC is available for evaluation on the following platforms:

- Lattice ECP5 based platforms
- HDR60 ECP3 based video eval board
- TE0600 (Spartan6 based) core module

A few resource usage examples are displayed in the tables below. The number of used EBR (Block RAM instances) can be reduced if no extended buffering is required.

Tab. 3: Required DSP components

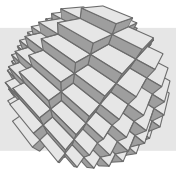
Module ID	MULT18X18D	ALU54B
JPEG	16	0
CPK	9	3
(Total SoC)	25	3

Tab. 4: Resource usage ECP5 'test bench'

Lattice ECP5	
SLICE	6172
Registers	4896
LUT4	6803
EBR	107

Tab. 5: Resource usage ECP3 'full MJPEG IPcam reference design'

Lattice ECP3	
SLICE	9848
Registers	5774
LUT4	15904
EBR	122



8 HDR60 demo

This demo is based on the standard 'off the shelf' configuration of the HDR60. It demonstrates the compression and transmission over a RFC2435 compliant MJPEG UDP video protocol. A Linux set up is recommended for the default test, however it is possible to run the demo on a gstreamer-1.0 Windows installation as well, using Teraterm or similar terminal software instead of **minicom**.

Note that 1GBit connections are not enabled and the demo firmware will attempt to configure the interface for 100M speed. This is verified by checking the connector LEDs: When the left LED on the RJ45 network connector is dark orange, the port is configured for 100 MB, when in 1G mode, it lights up green/yellow. To force an ethernet interface to 100M from a Linux host's side, you may have to install the **ethtool** and configure your MAC as follows:

```
sudo ethtool -s eth1 speed 100 duplex full autoneg off
```

8.1 Usage

1. Start gstreamer client on host (see configuration below)
2. Connect to UART console of target using minicom:

   ```
   minicom -o -D /dev/ttyUSB1 -b 115200
   ```

3. Configure target host in the 192.168.0.x network, like

   ```
   r 192.168.0.2
   ```

   Make sure to check if the target host responds, like:

   ```
   Send ARP request...
   # Got ARP reply: 3c aa aa 15 ce 34
   ```

4. Run (preset) JPEG stream @20fps:

   ```
   j 0
   ```

Currently, there are the following preset slots for the 'j' command:

0 1024x768@20fps, quality 90%

1 1024x768@10fps, quality 96%

2 1024x768@35fps, quality 80% (network limit)

3 1280x960@35fps, quality 75% (network limit)

8 1280x960@10fps, quality 80%, test pattern (see Fig. 1)

It is possible that some scenes cause FIFO overflows in the high bandwidth settings, for example the texture of a colourful fabric can have a similar effect as the pseudo random JPEG stress pattern.

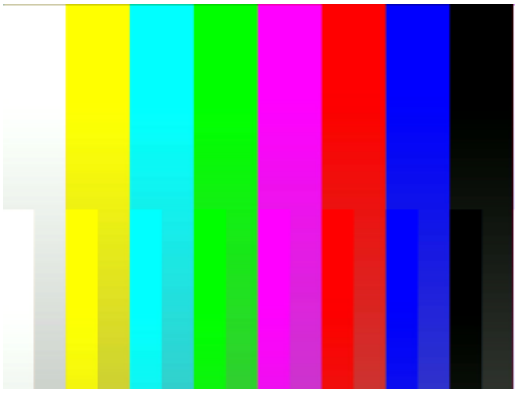


Fig. 1: 1280x960 sensor test pattern

8.1.1 GStreamer 1.0 Linux configuration

To display a test video stream, launch a gstreamer RTP pipeline on your development PC:

```
#!/bin/bash

caps="application/x-rtp, media=\(string\)video,"
caps="$caps clock-rate=\(int\)90000,"
caps="$caps encoding-name=\(string\)JPEG"
gst-launch-1.0 -v rtpbin name=rtpbin udpsrc \
caps="$caps" \
port=2020 \
! rtpbin.recv_rtp_sink_1 rtpbin. \
! rtpjpegdepay \
! jpegdec \
! fpsdisplaysink text-overlay=true sync=true \
    video-sink=autovideosink \
    signal-fps-measurements=true
```

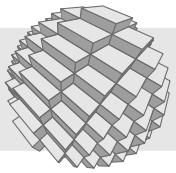
For a legacy gstreamer-0.10 installation, replace the plugin 'rtpbin' by 'gstrtpbin'.

To launch the test manually from the UART console shell on the FPGA SoC target, use the 'j' command. Note that arguments are in hexadecimal notation and should be a multiple of 16 (trailing '0'), otherwise they will be truncated. This command runs a JPEG stream at 1024x768:

```
j 400 300
```

You can tweak the framerate by changing the value of register `Reg_MFR_FRAME_LENGTH_LINES` (0x300a), see also parameters below. Likewise, you can modify the `Reg_MFR_LINE_LENGTH_PCK` (0x300c) register to experiment with the framerate on a grainier level.

It may be required to restart the gstreamer script when the video parameters are changed. Some settings can cause the sensor to hang and the JPEG stream may stall or look corrupt. Because the JPEG stream is generated by an internal, software-controlled engine, time consuming



operations may cause stream interruptions in this demo firmware. If the system stops streaming and locks up, i.e. turning off and back on using 'j' has no effect, press the reset button on the HDR60 to reinitialize.

Note that the fpsdisplaysink introduces some display latency. This is normal.

8.1.2 GStreamer 1.0 for Windows

For video streaming to a Windows platform, you can use the same script as above. The recommended installer is found in the download section of https://gstreamer.freedesktop.org/, either 32 or 64 bit should work.

After installation, you can run the script from the PowerShell, likewise. The installer sets the `GSTREAMER_1_0_ROOT_X86` variable for a 32 bit installation, so you can access the gst-launch binary directly by:

```
$env:GSTREAMER_1_0_ROOT_X86/bin/gst-launch-1.0
```

8.2 Sensor parameters

Using the 'i' command, you can control the MT9M024 sensor registers. When specifying only the register address as argument, its value will be dumped:

```
# i 3082
> 0028
```

Examples:

`i 3070 3`
: Turns on the test pattern

`i 3082 3`
: Turn off HDR, switch to linear mode

`i 3012 80`
: Modify exposure time

`i 300c 800`
: Change line timing (frame rate). Too high frame rates may cause FIFO overflow warnings on the console:

```
[FIFO]
```

8.3 Command line parameters

All numeric parameters are given in hexadecimal values

h Lists available commands. N/A in streaming mode.

r 192.168.0.<host_digit>
: Set receiver host by ip (preferrably in 192.168.0.x network)

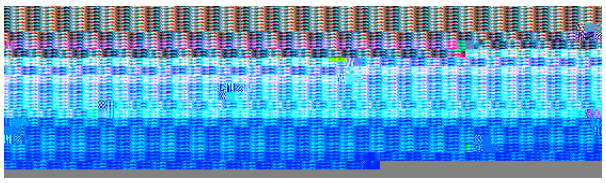


Fig. 2: FIFO full scenario

q <quantisation factor in hex>
: Set quantisation parameter from 1 (best quality) to 0x50 (worst)

j <preset>
: Call preset from 1-5. These are predefined test values for quality and resolution. If no preset is entered, the default will be used.

j <x> <y>
: Run stream with resolution x and y with the current quality setting

The resolution in x is limited to maximum 1280 in the defa

j Turn off stream when running

i <reg> [<data>]
: Get or set sensor value

is Initialize sensor default values (reset). N/A during streaming.

9 Diagnostics

The JPEG L2 SoC can be configured as test bench for FIFO and encoder stress tests to determine empirical compression limits. This is achieved by the so called 'stress pattern': A marching pseudo random pattern with a periodicity that results in a very bad compression rate and high load in the encoder pipeline. Details are found in the dombert SoC hardware reference. Note that the LFSR stress test is not available when an imaging sensor is present.

9.1 Error scenarios

Errors may occur during streaming. If the bandwidth of the Ethernet port (when in 100M mode) is not sufficient, FIFO overflows will be signalled and the image will look broken as in example Fig. 2 (LFSR stress test).

The displayed console (UART) errors in detail:

[FIFO]
: Denotes that FIFO overrun flag was set. This occurs when the FIFO between JPEG and DMA can not take more data when the network MAC TX is busy. Increase the "quantisation" value ('q' command) or reduce resolution.

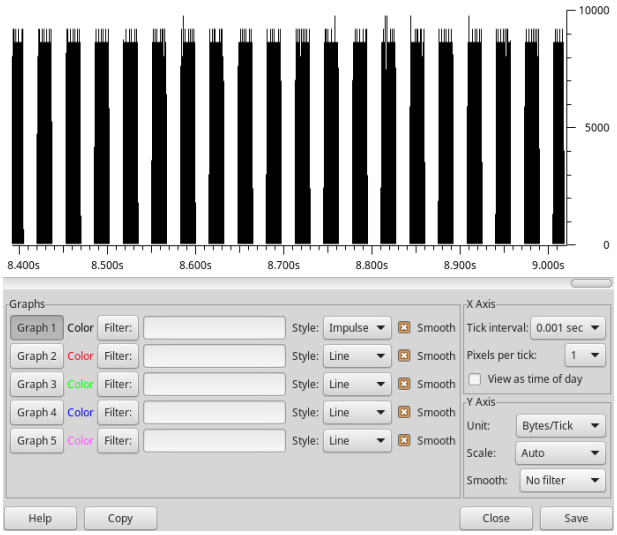


Fig. 3: Sane packet burst at approx 30 fps

[DEMUX]
: Can only fail on misconfiguration of the encoder or at the very beginning of a sequence, if the image stream is not started synchronously.

[DCT_ERR]
: Can only occur when input data is faulty in 12 bit mode (N/A in demo)

[DCT_OVER]
: Can only occur on misconfiguration of the encoder or sensor (wrong image width or wrong number of MCUs specified).

9.2 Packet stream analysis

There are scenarios where the generated demo image may show broken for the following reasons:

- Packets are lost:
  - Packet drop on router side
  - Network congestion or interface issues
- FIFO overrun on the encoder side has occurred
  - Network is busy due to other network devices creating traffic
  - JPEG quality bandwidth excess (see previous paragraph)

To analyze the network packet stream, it is recommended to use the **Wireshark** analyzer on a Linux platform.

Fig. 3 shows a typical 'stress pattern' packet stream during a flawless JPEG transmission on a 100M link without interference by other network participants. The physical maximum of approx. 10'000 Bytes per tick (0.001s) during the packet bursts is not fully reached, leaving some headroom for the output FIFO.

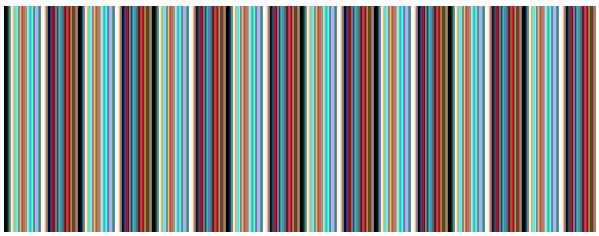


Fig. 4: Regular pattern at x=672 (0x2a0)

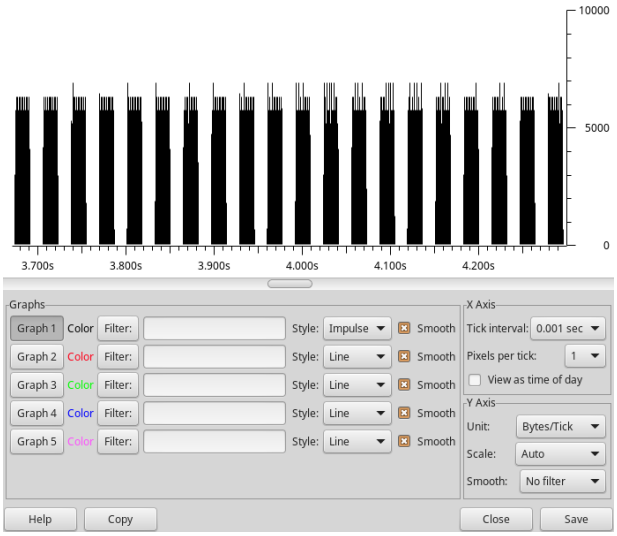


Fig. 5: Low bandwidth packet burst at approx 30 fps

When a width of a multiple of 336 (e.g. **j 150 200** on the console) is used, the stress pattern does not march and is the same for every line as display in Fig. 4, i.e. the compression is more effective. The corresponding packet sequence is display in Fig. 5.

10 Further pointers

[RFC2435] RTP Payload Format for JPEG-compressed Video
: http://www.faqs.org/rfcs/rfc2435.html

Web link
: https://section5.ch/index.php/documentation/masocist-soc/

dombert Hardware Reference `soc-dombert.pdf`
: Detailed developer manual for the Dombert SoC