



Gowin MJPEG Encoder IP

User Guide

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1 About This Guide

1.1 Purpose

The purpose of Gowin MJPEG Encoder IP User Guide is to help you learn the features and usage of Gowin MJPEG Encoder IP by providing the descriptions of functions, ports, timing, GUI and reference design, etc.

1.2 Related Documents

You can find the related documents at GOWINSEMI website www.gowinsemi.com:

- [DS102, GW2A series of FPGA Products Data Sheet](#)
- [DS226, GW2AR series of FPGA Products Data Sheet](#)
- [DS971, GW2AN series of FPGA Products Data Sheet](#)
- [SUG100, Gowin Software User Guide](#)

1.3 Terminology and Abbreviations

The terminology and abbreviations used in this manual are as shown in Table 1-1.

Table 1-1 Terminology and Abbreviations

Terminology and Abbreviations	Meaning
FPGA	Field Programmable Gate Array
IP	Intellectual Property
DSP	Digital Signal Processing
SRAM	Static Random Access Memory
BSRAM	Block Static Random Access Memory
MJPEG	Motion Joint Photographic Experts Group
CSC	Color Space Convert
DUS	Data Unit Segmentation
DCT	Discrete Cosine Transform
VLI	Variable Length Integer

1.4 Support and Feedback

Gowin Semiconductor provides customers with comprehensive technical support. If you have any questions, comments, or suggestions, please feel free to contact us directly by the following ways.

Website: www.gowinsemi.com

E-mail: support@gowinsemi.com

2 Overview

2.1 Introduction to Gowin MJPEG Encoder IP

Gowin MJPEG Encoder IP is a Motion Joint Photographic Experts Group (MJPEG) encoder that can convert RGB images to YCbCr format and implements dynamic compression based on JPEG encoding.

Table 2-1 Gowin MJPEG Encoder IP Overview

MJPEG Encoder IP	
IP Core Application	
Supported Devices	● GW2A series ● GW2AR series ● GW2ANR series
Logic Resource	Please refer to Table 2-2.
Delivered Doc.	
Design Files	Verilog (encrypted)
Reference Design	Verilog
TestBench	Verilog
Test and Design Flow	
Synthesis Software	GowinSynthesis
Application Software	Gowin Software (V1.9.8.03 and above)

2.2 Features

- Supports 64*64~1920x1080 pixels of input images
- Supports 24 bits data width of input images
- Supports 8 bits data width of output images

2.3 Max. Frequency

The maximum frequency of Gowin MJPEG Encoder IP is mainly determined by the speed grade of the devices and configuration parameters. When GW2A-18 series of devices used, it can be up to 90MHz.

2.4 Latency

The latency of Gowin MJPEG Encoder IP is usually one clock cycle.

2.5 Resource Utilization

Gowin MJPEG Encoder IP resource utilization mainly depends on the size of image, etc. The resource utilization may be different with different devices.

Taking GW2A-18 series of FPGA as an example, Gowin MJPEG Encoder IP resource utilization is as shown in Table 2-2.

Table 2-2 Resource Utilization (GW2A-18 C8/I7)

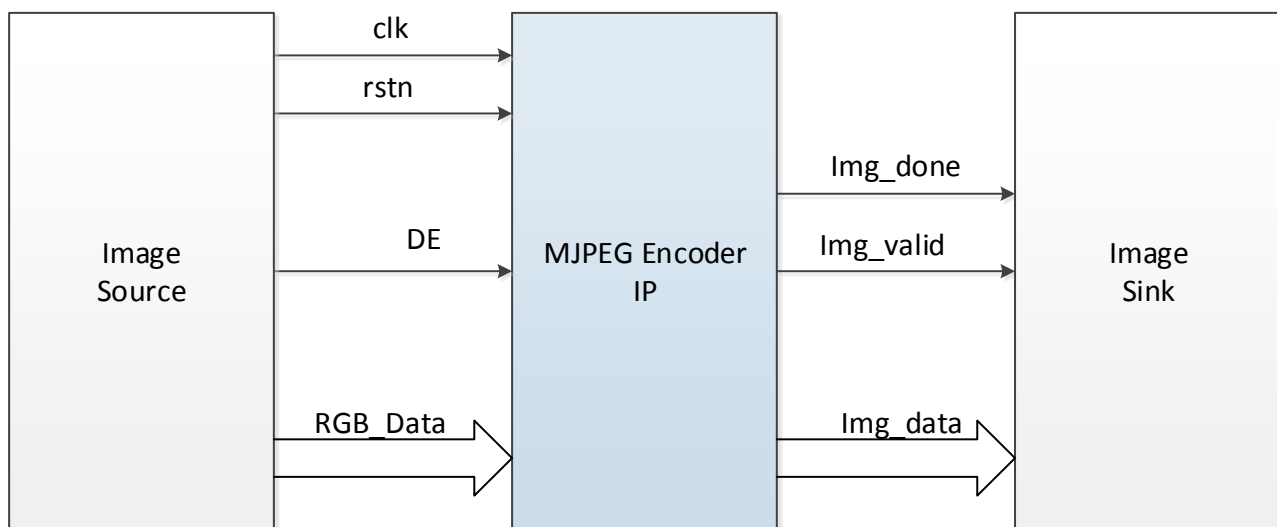
Frame Size	LOGICs	REGs	DSP Macros	BSRAMs	SSRAMs
640*480	6091	5833	3	26	43

3 Functional Description

3.1 System Block Diagram

Gowin MJPEG Encoder IP receives RGB image data from the image source and outputs it after color space conversion, data unit segmentation, discrete cosine transform, quantization, ZigZag, entropy encoding, etc. The system block diagram is shown in Figure 3-1.

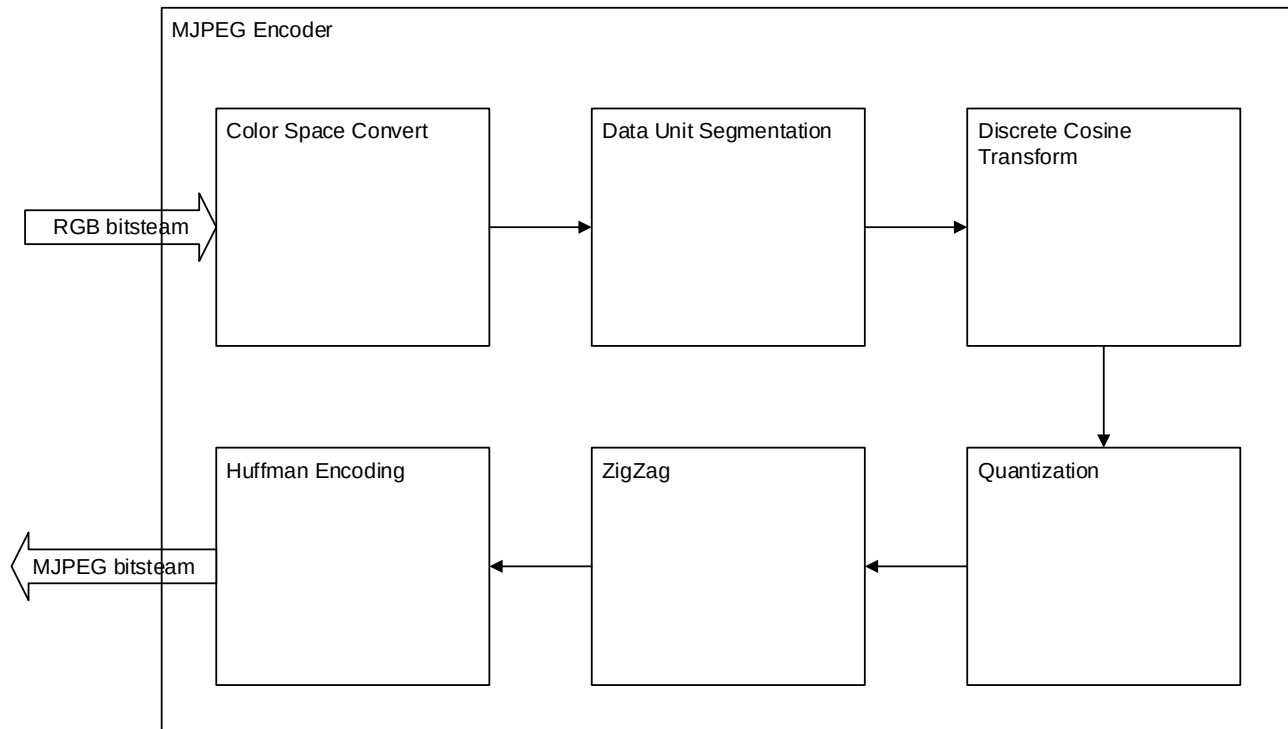
Figure 3-1 System Block Diagram



3.2 Structure Diagram

The structure diagram of Gowin MJPEG Encoder IP is shown in Figure 3-2.

Figure 3-2 Structure Diagram



3.3 Structure Diagram Description

3.3.1 Color Space Conversion

Color Space Convert converts RGB data to YCbCr data. The conversion can be expressed as:

$$\begin{pmatrix} Y \\ Cb \\ Cr \end{pmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ -0.1687 & -0.3313 & 0.5 \\ 0.5 & -0.4187 & -0.0813 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 0 \\ 128 \\ 128 \end{bmatrix}$$

3.3.2 Data Unit Segmentation

Data Unit Segmentation segments the image into 8*8 pixel data units to facilitate DCT operations.

3.3.3 Discrete Cosine Transform

Discrete Cosine Transform transforms an image from time domain to frequency domain. It can be expressed as:

$$F(u, v) = Af(x, y)A^T$$

$f(x, y)$ is the 8*8 sample data; A is the 8*8 coefficient matrix, and $F(x, y)$ is the result of the transformation. The formula for each element in A is as follows.

$$A_{xy} = C_x \cos \frac{(2y+1)x\pi}{16}$$

$$C(x) = \begin{cases} \sqrt{\frac{1}{8}}, & x = 0 \\ \sqrt{\frac{1}{4}}, & x \neq 0 \end{cases}$$

The expanded calculation formula is as follows.

$$F(u, v) = \frac{1}{4} C(u) C(v) \sum_{x=0}^7 \sum_{y=0}^7 f(x, y) \cos\left[\frac{(2X+1)\pi}{16} u\right] \cos\left[\frac{(2y+1)\pi}{16} v\right]$$

$$C(x) = \begin{cases} \sqrt{\frac{1}{2}}, & x = 0 \\ 1, & x \neq 0 \end{cases}$$

$f(x)$ is an 8*8 data unit; $F(u)$ is the coefficient after DCT, and $c(u)$ is a compensation coefficient that can make the DCT matrix transform to orthogonal matrix.

The above operation needs two matrix multiplications, so it is also called two-dimensional DCT, which can be realized by two one-dimensional DCTs. First, calculate $Z=Af(x, y)$, and the result is transformed and cached to get Z^T . After reading the cached result, one-dimensional DCT $F(x, y)T=ZTAT$ is performed again, and the result is transformed and cached to get $F(x, y)$, the result of two-dimensional DCT.

3.3.4 Quantization

Quantization means the division of the DCT variation coefficients by the quantization step to reduce the precision of the DCT coefficients. Since human eyes are more sensitive to the perception of changes in the low-frequency components than the high-frequency components, the JPEG standard uses unequal quantization, and the quantization can be expressed as follows.

$$FQ(x, y) = \text{round}\left(\frac{F(x, y)}{Q(x, y)}\right)$$

$F(x, y)$ is the DCT coefficient, $Q(x, y)$ is the quantization coefficient, and

$FQ(x,y)$ is the quantization result.

Two recommended quantitation tables are shown below.

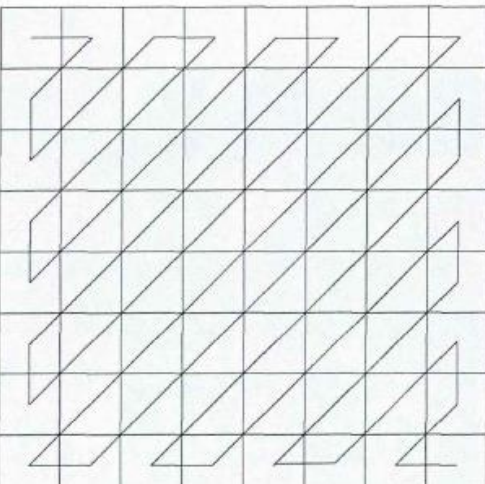
Figure 3-3 Standard Luminance/Chrominance Quantization Table

Luminance								Chrominance							
16	11	10	16	24	40	51	61	17	18	24	47	99	99	99	99
12	12	14	19	26	58	60	55	18	21	26	66	99	99	99	99
14	13	16	24	40	57	69	56	24	16	56	99	99	99	99	99
14	17	22	29	51	87	80	62	47	66	99	99	99	99	99	99
18	22	37	56	68	109	103	77	99	99	99	99	99	99	99	99
24	35	55	64	81	104	113	92	99	99	99	99	99	99	99	99
49	64	78	87	103	121	120	101	99	99	99	99	99	99	99	99
72	92	95	98	112	100	103	99	99	99	99	99	99	99	99	99

3.3.5 ZigZag

The quantized coefficients have a large number of zero-valued coefficients; in order to enhance the effect of Run Length Encoding, the quantized coefficients need to be reordered, as shown below.

Figure 3-4 ZigZag



The diagram shows an 8x8 grid with a zigzag path starting from the top-left corner (0,0) and ending at the bottom-right corner (7,7). The path is indicated by a series of connected line segments forming a continuous zigzag pattern. The path starts at (0,0), goes right to (1,0), then down to (1,1), then right to (2,1), then down to (2,2), then right to (3,2), then down to (3,3), then right to (4,3), then down to (4,4), then right to (5,4), then down to (5,5), then right to (6,5), then down to (6,6), then right to (7,6), and finally down to (7,7).

0	1	5	6	14	15	27	28
2	4	7	14	16	26	29	42
3	8	12	17	25	30	41	43
9	11	18	24	31	40	44	53
10	19	23	32	39	45	52	54
20	22	33	38	46	51	55	60
21	34	37	47	50	56	59	61
35	36	48	49	57	58	62	63

3.3.6 Huffman Encoding

Entropy coding mainly contains differential encoding, run length encoding, Huffman encoding, etc.

First define DC component and AC component. In a ZigZag-transformed 8*8 data unit, the data at the (0, 0) is DC and the rest of the data is AC. DC represents the average value of the data before the transformation of the block, and the DC components of the adjacent blocks

tend to be close to each other. The first value of AC tends to be the maximum of all AC components, representing the AC component that has the greatest impact on the image. There are often a large number of consecutive zeros preceding a non-zero AC component, and the AC component will usually end up with all zeros.

Differential encoding is performed mainly for DC. Only the DC of the first data unit of each type is kept for each image, and the DC of the remaining data units is represented by the difference of the DC of the previous data unit. That is:

$$DIFF = DC_i - DC_{i-1}$$

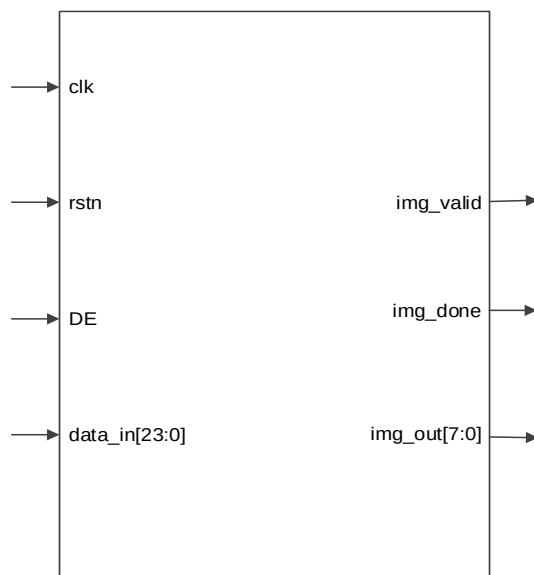
Run length encoding is performed mainly for AC. A series of RUN/LEVEL pairs are used to represent the data flow, where RUN indicates the number of zeros preceding the non-zero data and LEVEL indicates the size of the non-zero data. If the number of AC that is consecutive zeros scanned by Zigzag is greater than 15, then 15/0 is used to represent the consecutive 16 zeros, and 15/0 is called Zero Run Length. If Zigzag scans a non-zero data, behind which all the data are 0, the End of Block (EOB) signal is generated, which indicates the early end of the data unit.

In Huffman encoding, the RUN/SIZE values that occur more frequently are represented as shorter code words, and those that occur less frequently as longer code words. JPEG standard places further restrictions on the Huffman code words and is called the standard Huffman. For the details, you can see [9.2 Standard Huffman Table](#).

4 Port Description

The I/O ports of Gowin MJPEG Encoder IP are shown in Figure 4-1.

Figure 4-1 I/O Ports



For the details, you can see Table 4-1.

Table 4-1 I/O List

Signal	I/O	Data Width	Description
clk	I	1	Input clock signal
rstn	I	1	Reset signal, active-low.
DE	I	1	Input data valid signal
data_in	I	24	Input image data signal
img_valid	O	1	Output valid signal, active-high.
img_out	O	8	Output image data signal
img_done	O	1	Output image frame done signal

5 Timing Description

This chapter mainly introduces the timing of Gowin MJPEG Encoder IP.

The data output of Gowin MJPEG Encoder IP includes two parts; the header file is output first and then the compressed data is output. The first 623 valid data of each image frame are the header file, and the remaining is the compressed data.

After operation, data will be output the data with a delay. The header file is usually delayed by one clock cycle and the timing is as shown in Figure 5-1. The compressed data is usually delayed by $(8 * \text{Maximum_Columns} + 175)$ clock cycles and the timing is as shown in Figure 5-2.

Figure 5-1 Timing Diagram of the Header File

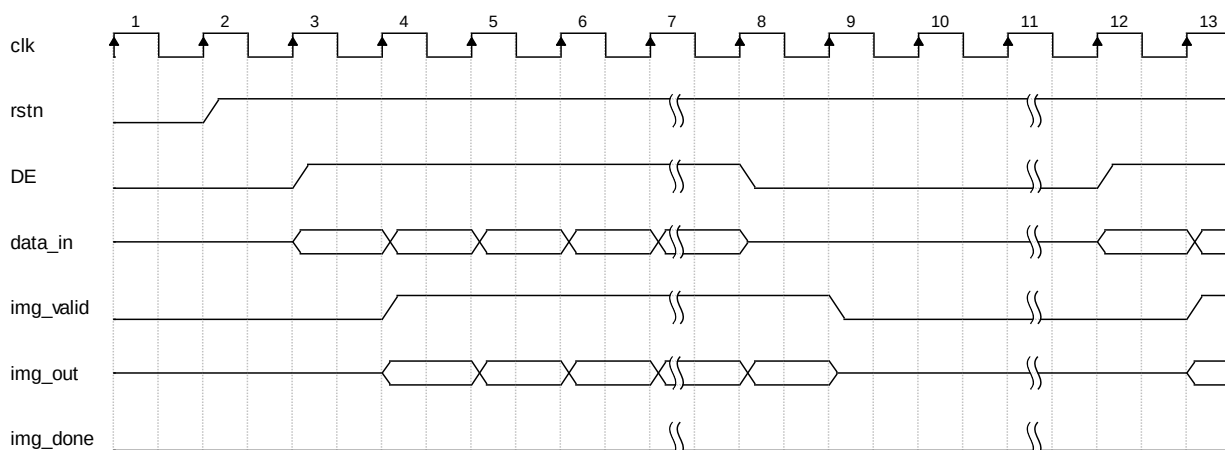
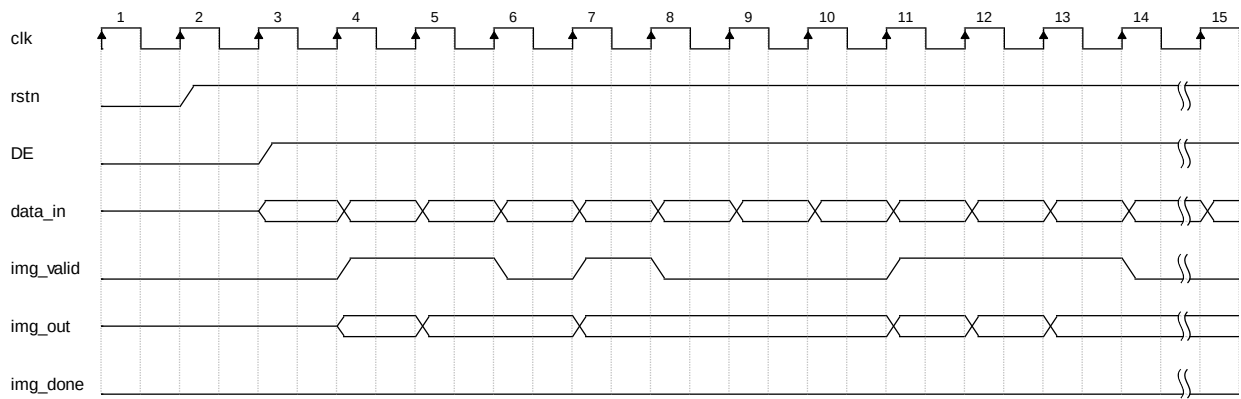
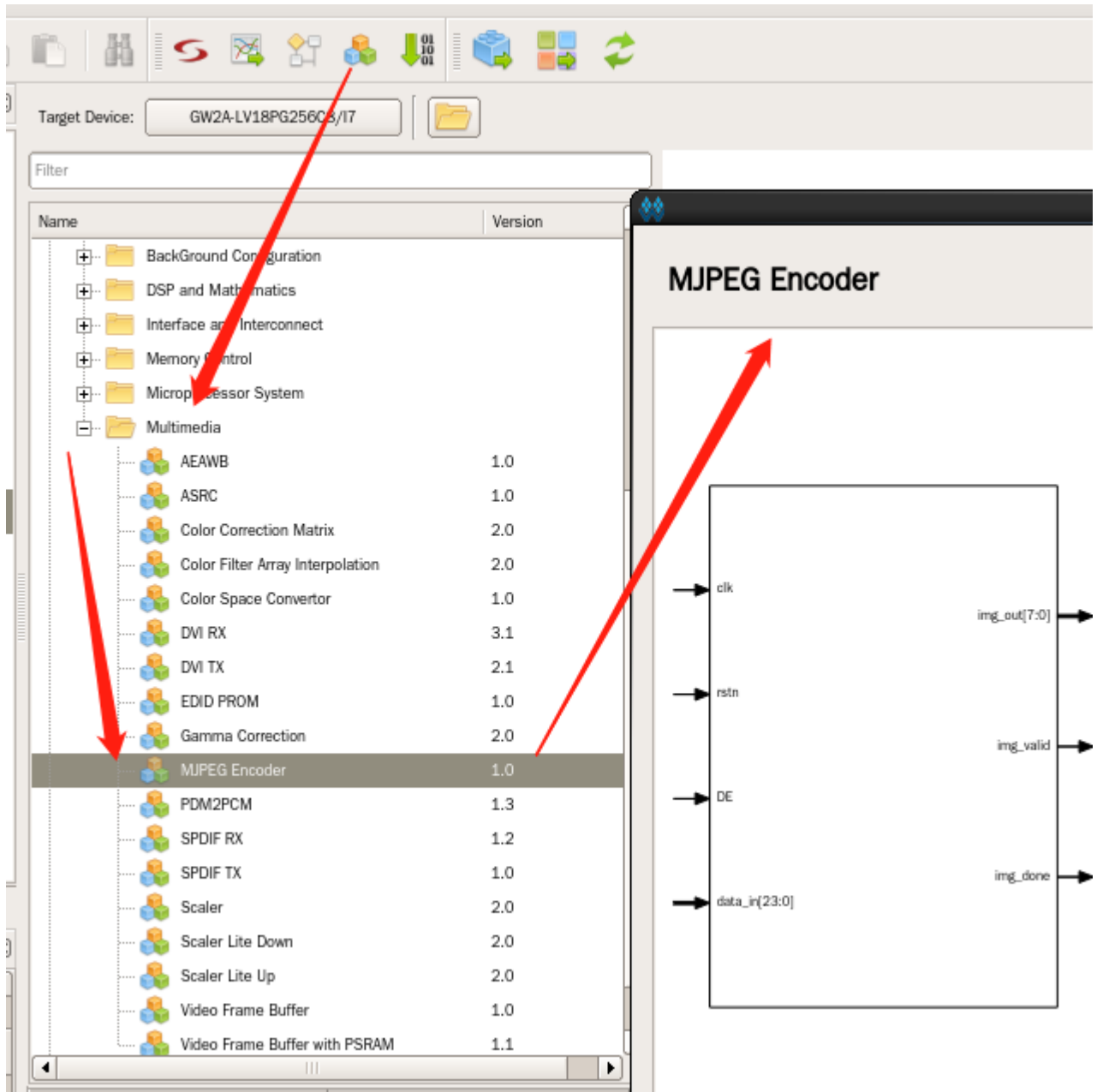


Figure 5-2 Timing Diagram of the Compressed Data

6 Call and Configure IP

Click "Tools > IP Core Generator > Multimedia > MJPEG Encoder" to call and configure Gowin MJPEG Encoder IP; toolbar icon is also available as shown in Figure 6-1 .

Figure 6-1 Open GUI by Clicking Icon



The configuration interface of Gowin MJPEG Encoder IP is as shown in Figure 6-2.

Figure 6-2 Configuration Interface

MJPEG Encoder

General

Device: GW2A-18 Part Number: GW2A-LV18PG256C8/I7

Create In: /sim/users/tpga_project/src/mjpeg_encoder

File Name: mjpeg_encoder Module Name: MJPEG_Encoder_Top

Language: Verilog Synthesis Tool: GowinSynthesis

Options

Data Options

Maximum Columns: 64 (64-1920, multiple of 8)

Maximum Rows: 64 (64-1080, multiple of 8)

Generation Config

☒ Disable I/O Insertion

Cancel OK

- In the "File Name" field, you can enter the generated IP file name.
- In the "Module Name" field, you can enter the generated IP module name.
- In "Options", you can configure IP working mode, etc.

Gowin MJPEG Encoder IP configuration options are shown in Table 6-1.

Table 6-1 Configuration Options

Options	Description
Maximum Columns	The number of input image columns
Maximum Rows	The number of input image rows

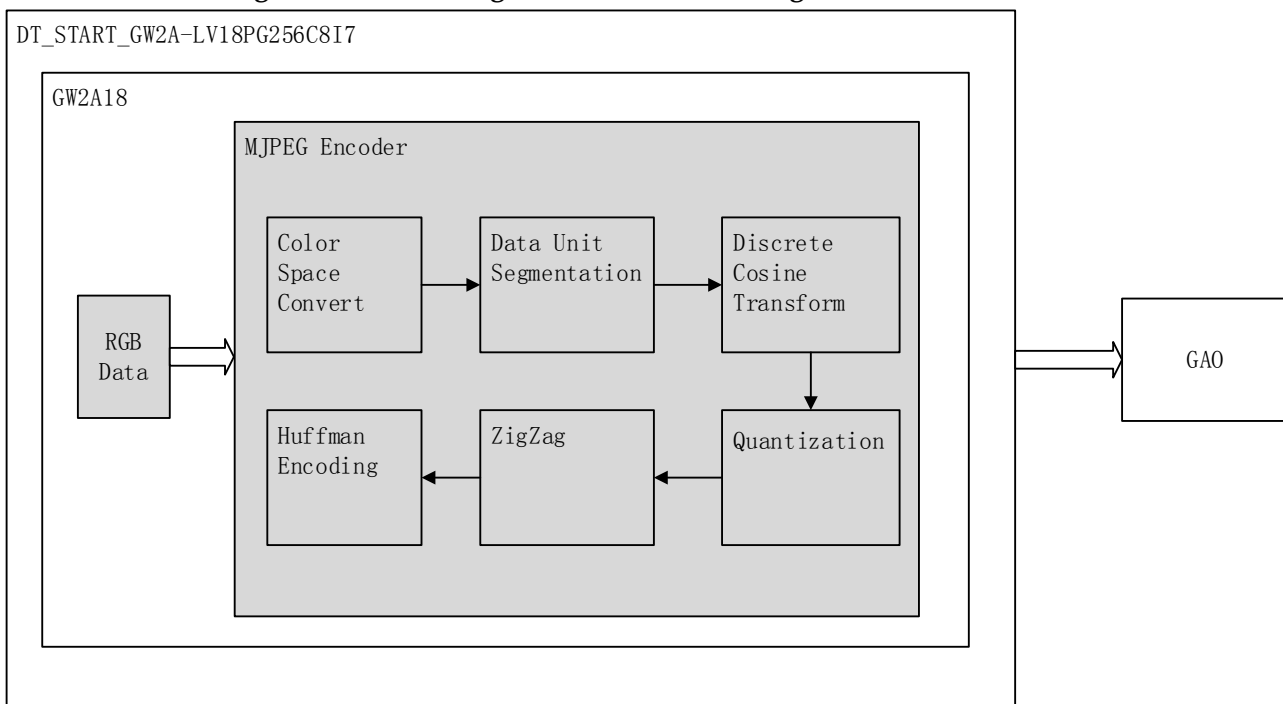
7 Reference Design

Please refer to the related test cases in [RefDesign](#).

Application

Gowin MJPEG Encoder IP functions can be verified using this design example. When the reference design is applied to board-level testing, you need to provide appropriate stimulus to the reference design and use an on-line logic analyzer or oscilloscope to observe the signals.

Figure 7-1 Block Diagram of Reference Design



RGB Data is used to generate RGB data and GAO is used to observe the output data.

8 File Delivery

The delivery file of Gowin MJPEG Encoder IP includes documentation and reference design.

8.1 Documentation

The documentation mainly contains the user guide and release note in PDF version.

Table 8-1 Documentation List

Name	Description
IPUG794, Gowin MJPEG Encoder IP User Guide	Gowin IP User Guide, namely this one.
RN794, Gowin MJPEG Encoder IP Release Note	Gowin IP User Guide Release Note

8.2 Reference Design

The Ref. Design folder contains the netlist file, the user reference design, the constraints file, the top file, and the project folder, etc.

Table 8-2 Ref. Design File List

Name	Description
mjpeg_exp.v	Top module and stimulus generation module of reference design
mjpeg_encoder.vo	Netlist file
demo.cst	Physical constraints file
fpga_project.sdc	Timing constraints file
fpga_project.rao	Capture output data of MJPEG Encoder
mjpeg_encoder	Project file

9 Appendix

9.1 Standard DCT Coefficient Matrix

The values of the coefficient matrix A in the DCT are as follows.

$$A = \begin{bmatrix} a & a & a & a & a & a & a & a \\ b & d & e & g & -g & -e & -d & -b \\ c & f & -f & -c & -c & -f & f & c \\ d & -g & -b & -e & e & b & g & -d \\ a & -a & -a & a & a & -a & -a & a \\ e & -b & g & d & -d & -g & b & -e \\ f & -c & c & -f & -f & c & -c & f \\ g & -e & d & -b & b & -d & e & -g \end{bmatrix}$$

$$\begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ g \end{bmatrix} = \frac{1}{2} \begin{bmatrix} \cos(4\pi/16) \\ \cos(\pi/16) \\ \cos(2\pi/16) \\ \cos(3\pi/16) \\ \cos(5\pi/16) \\ \cos(6\pi/16) \\ \cos(7\pi/16) \end{bmatrix}$$

9.2 Standard Huffman Table

9.2.1 Luminance DC Huffman Code Table Recommended by JPEG

Table 9-1 Luminance DC Huffman Code Table Recommended by JPEG

Category	Code length	Code word
0	2	00
1	3	010
2	3	011
3	3	100
4	3	101
5	3	110
6	4	1110
7	5	11110
8	6	111110

Category	Code length	Code word
9	7	1111110
10	8	11111110
11	9	111111110

9.2.2 Chrominance DC Huffman Code Table Recommended by JPEG

Table 9-2 Chrominance DC Huffman Code Table Recommended by JPEG

Category	Code length	Code word
0	2	00
1	2	01
2	2	10
3	3	110
4	4	1110
5	5	11110
6	6	111110
7	7	1111110
8	8	11111110
9	9	111111110
10	10	1111111110
11	11	11111111110

9.2.3 Luminance AC Huffman Code Table Recommended by JPEG

Table 9-3 Luminance AC Huffman Code Table Recommended by JPEG

Run/Size	Code length	Code word
0/0 (EOB)	4	1010
0/1	2	00
0/2	2	01
0/3	3	100
0/4	4	1011
0/5	5	11010
0/6	7	1111000
0/7	8	11111000
0/8	10	1111110110
0/9	16	1111111110000010
0/A	16	1111111110000011
1/1	4	1100
1/2	5	11011
1/3	7	1111001
1/4	9	111110110
1/5	11	11111110110
1/6	16	1111111110000100
1/7	16	1111111110000101
1/8	16	1111111110000110
1/9	16	1111111110000111
1/A	16	1111111110001000
2/1	5	11100
2/2	8	11111001
2/3	10	1111110111
2/4	12	111111110100
2/5	16	1111111110001001
2/6	16	1111111110001010
2/7	16	1111111110001011
2/8	16	1111111110001100
2/9	16	1111111110001101
2/A	16	1111111110001110
3/1	6	111010
3/2	9	111110111
3/3	12	111111110101
3/4	16	1111111110001111
3/5	16	1111111110010000
3/6	16	1111111110010001
3/7	16	1111111110010010
3/8	16	1111111110010011

Run/Size	Code length	Code word
3/9	16	1111111110010100
3/A	16	1111111110010101
4/1	6	111011
4/2	10	1111111000
4/3	16	1111111110010110
4/4	16	1111111110010111
4/5	16	1111111110011000
4/6	16	1111111110011001
4/7	16	1111111110011010
4/8	16	1111111110011011
4/9	16	1111111110011100
4/A	16	1111111110011101
5/1	7	1111010
5/2	11	11111110111
5/3	16	1111111110011110
5/4	16	1111111110011111
5/5	16	1111111110100000
5/6	16	1111111110100001
5/7	16	1111111110100010
5/8	16	1111111110100011
5/9	16	1111111110100100
5/A	16	1111111110100101
6/1	7	1111011
6/2	12	111111110110
6/3	16	1111111110100110
6/4	16	1111111110100111
6/5	16	1111111110101000
6/6	16	1111111110101001
6/7	16	1111111110101010
6/8	16	1111111110101011
6/9	16	1111111110101100
6/A	16	1111111110101101
7/1	8	11111010
7/2	12	111111110111
7/3	16	1111111110101110
7/4	16	1111111110101111
7/5	16	1111111110110000
7/6	16	1111111110110001
7/7	16	1111111110110010
7/8	16	1111111110110011
7/9	16	1111111110110100

Run/Size	Code length	Code word
7/A	16	111111110110101
8/1	9	11111000
8/2	15	11111111000000
8/3	16	111111110110110
8/4	16	111111110110111
8/5	16	111111110111000
8/6	16	111111110111001
8/7	16	111111110111010
8/8	16	111111110111011
8/9	16	111111110111100
8/A	16	111111110111101
9/1	9	11111001
9/2	16	111111110111110
9/3	16	111111110111111
9/4	16	111111111000000
9/5	16	111111111000001
9/6	16	111111111000010
9/7	16	111111111000011
9/8	16	111111111000100
9/9	16	111111111000101
9/A	16	111111111000110
A/1	9	11111010
A/2	16	111111111000111
A/3	16	111111111001000
A/4	16	111111111001001
A/5	16	111111111001010
A/6	16	111111111001011
A/7	16	111111111001100
A/8	16	111111111001101
A/9	16	111111111001110
A/A	16	111111111001111
B/1	10	111111001
B/2	16	111111111010000
B/3	16	111111111010001
B/4	16	111111111010010
B/5	16	111111111010011
B/6	16	111111111010100
B/7	16	111111111010101
B/8	16	111111111010110
B/9	16	111111111010111
B/A	16	111111111011000

Run/Size	Code length	Code word
C/1	10	1111111010
C/2	16	1111111111011001
C/3	16	1111111111011010
C/4	16	1111111111011011
C/5	16	1111111111011100
C/6	16	1111111111011101
C/7	16	1111111111011110
C/8	16	1111111111011111
C/9	16	1111111111000000
C/A	16	1111111111000001
D/1	11	11111111000
D/2	16	111111111100010
D/3	16	111111111100011
D/4	16	111111111100100
D/5	16	111111111100101
D/6	16	111111111100110
D/7	16	111111111100111
D/8	16	111111111101000
D/9	16	111111111101001
D/A	16	111111111101010
E/1	16	111111111101011
E/2	16	111111111101100
E/3	16	111111111101101
E/4	16	111111111101110
E/5	16	111111111101111
E/6	16	11111111110000
E/7	16	111111111100001
E/8	16	111111111100010
E/9	16	111111111100011
E/A	16	11111111110100
F/0 (ZRL)	11	11111111001
F/1	16	111111111110101
F/2	16	111111111110110
F/3	16	111111111110111
F/4	16	11111111111000
F/5	16	11111111111001
F/6	16	11111111111010
F/7	16	11111111111011
F/8	16	11111111111100
F/9	16	11111111111101
F/A	16	11111111111110

9.2.4 Chrominance AC Huffman Code Table Recommended by JPEG

Table 9-4 Chrominance AC Huffman Code Table Recommended by JPEG

Run/Size	Code length	Code word
0/0 (EOB)	2	00
0/1	2	01
0/2	3	100
0/3	4	1010
0/4	5	11000
0/5	5	11001
0/6	6	111000
0/7	7	1111000
0/8	9	111110100
0/9	10	1111110110
0/A	12	111111110100
1/1	4	1011
1/2	6	111001
1/3	8	11110110
1/4	9	111110101
1/5	11	11111110110
1/6	12	111111110101
1/7	16	1111111110001000
1/8	16	1111111110001001
1/9	16	1111111110001010
1/A	16	1111111110001011
2/1	5	11010
2/2	8	11110111
2/3	10	1111110111
2/4	12	111111110110
2/5	15	111111111000010
2/6	16	1111111110001100
2/7	16	1111111110001101
2/8	16	1111111110001110
2/9	16	1111111110001111
2/A	16	1111111110010000
3/1	5	11011
3/2	8	11111000
3/3	10	1111111000
3/4	12	111111110111
3/5	16	1111111110010001
3/6	16	1111111110010010
3/7	16	1111111110010011
3/8	16	1111111110010100

Run/Size	Code length	Code word
3/9	16	1111111110010101
3/A	16	1111111110010110
4/1	6	111010
4/2	9	111110110
4/3	16	1111111110010111
4/4	16	1111111110011000
4/5	16	1111111110011001
4/6	16	1111111110011010
4/7	16	1111111110011011
4/8	16	1111111110011100
4/9	16	1111111110011101
4/A	16	1111111110011110
5/1	6	111011
5/2	10	1111111001
5/3	16	1111111110011111
5/4	16	1111111110100000
5/5	16	1111111110100001
5/6	16	1111111110100010
5/7	16	1111111110100011
5/8	16	1111111110100100
5/9	16	1111111110100101
5/A	16	1111111110100110
6/1	7	1111001
6/2	11	11111110111
6/3	16	1111111110100111
6/4	16	1111111110101000
6/5	16	1111111110101001
6/6	16	1111111110101010
6/7	16	1111111110101011
6/8	16	1111111110101100
6/9	16	1111111110101101
6/A	16	1111111110101110
7/1	7	1111010
7/2	11	11111111000
7/3	16	1111111110101111
7/4	16	1111111110110000
7/5	16	1111111110110001
7/6	16	1111111110110010
7/7	16	1111111110110011
7/8	16	1111111110110100
7/9	16	1111111110110101

Run/Size	Code length	Code word
7/A	16	1111111110110110
8/1	8	11111001
8/2	16	1111111110110111
8/3	16	1111111110111000
8/4	16	1111111110111001
8/5	16	1111111110111010
8/6	16	1111111110111011
8/7	16	1111111110111100
8/8	16	1111111110111101
8/9	16	1111111110111110
8/A	16	1111111110111111
9/1	9	111110111
9/2	16	1111111111000000
9/3	16	1111111111000001
9/4	16	1111111111000010
9/5	16	1111111111000011
9/6	16	1111111111000100
9/7	16	1111111111000101
9/8	16	1111111111000110
9/9	16	1111111111000111
9/A	16	1111111111001000
A/1	9	111111000
A/2	16	1111111111001001
A/3	16	1111111111001010
A/4	16	1111111111001011
A/5	16	1111111111001100
A/6	16	1111111111001101
A/7	16	1111111111001110
A/8	16	1111111111001111
A/9	16	1111111111010000
A/A	16	1111111111010001
B/1	9	111111001
B/2	16	1111111111010010
B/3	16	1111111111010011
B/4	16	1111111111010100
B/5	16	1111111111010101
B/6	16	1111111111010110
B/7	16	1111111111010111
B/8	16	1111111111011000
B/9	16	1111111111011001
B/A	16	1111111111011010

Run/Size	Code length	Code word
C/1	9	111111010
C/2	16	1111111111011011
C/3	16	1111111111011100
C/4	16	1111111111011101
C/5	16	1111111111011110
C/6	16	1111111111011111
C/7	16	1111111111100000
C/8	16	1111111111100001
C/9	16	1111111111100010
C/A	16	1111111111100011
D/1	11	11111111001
D/2	16	1111111111100100
D/3	16	1111111111100101
D/4	16	1111111111100110
D/5	16	1111111111100111
D/6	16	1111111111101000
D/7	16	1111111111101001
D/8	16	1111111111101010
D/9	16	1111111111101011
D/A	16	1111111111101100
E/1	14	11111111100000
E/2	16	1111111111101101
E/3	16	1111111111101110
E/4	16	1111111111101111
E/5	16	1111111111110000
E/6	16	1111111111110001
E/7	16	1111111111110010
E/8	16	1111111111110011
E/9	16	1111111111110100
E/A	16	1111111111110101
F/0 (ZRL)	10	1111111010
F/1	15	111111111000011
F/2	16	1111111111110110
F/3	16	1111111111110111
F/4	16	1111111111111000
F/5	16	1111111111111001
F/6	16	1111111111111010
F/7	16	1111111111111011
F/8	16	1111111111111100
F/9	16	1111111111111101
F/A	16	1111111111111110

9.2.5 Variable Length Integer Code Table of DC and AC Coefficients

Table 9-5 Variable Length Integer Code Table of DC and AC Coefficients

Value	Size	Bits
0	0	-
-1, 1	1	0, 1
-3, -2, 2, 3	2	00, 01, 10, 11
-7, -6, -5, -4, 4, 5, 6, 7	3	000, 001, 010, 011, 100, 101, 110, 111
-15, ..., -8, 8, ..., 15	4	0000, ..., 0111, 1000, ..., 1111
-31, ..., -16, 16, ..., 31	5	0 0000, ..., 0 1111, 1 0000, ..., 1 1111
-63, ..., -32, 32, ..., 63	6	00 0000, ..., ..., 11 1111
-127, ..., -64, 64, ..., 127	7	000 0000, ..., ..., 111 1111
-255, ..., -128, 128, ..., 255	8	0000 0000, ..., ..., 1111 1111
-511, ..., -256, 256, ..., 511	9	0 0000 0000, ..., ..., 1 1111 1111
-1023, ..., -512, 512, ..., 1023	10	00 0000 0000, ..., ..., 11 1111 1111
-2047, ..., -1024, 1024, ..., 2047	11	000 0000 0000, ..., ..., 111 1111 1111
-4095, ..., -2048, 2048, ..., 4095	12	0000 0000 0000, ..., ..., 1111 1111 1111
-8191, ..., -4096, 4096, ..., 8191	13	0 0000 0000 0000, ..., ..., 1 1111 1111 1111
-16383, ..., -8192, 8192, ..., 16383	14	00 0000 0000 0000, ..., ..., 11 1111 1111 1111
-32767, ..., -16384, 16384, ..., 32767	15	000 0000 0000 0000, ..., ..., 111 1111 1111 1111

