# Game Boy Camera Technical Information v1.0.1

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Antonio Niño Díaz (Antonio ND), 2015

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## 1 Introduction

Some years ago (about 2010) I tried to emulate the Game Boy Camera by using its ROM and the sensor datasheet (which is really bad). There was a lot to guess so I couldn't emulate it completely. Since there is no documentation about the Game Boy Camera I decided it was time to document it, but I really couldn't do much without doing tests in the cartridge itself.

This time I've used Arduino to send commands to the cartridge and to read the sensor pins to know how they are translated. This means that I can know how the controller works so I only need to know how the sensor works. I've used the datasheets from sensors M64283FP and M64285FP (the Game Boy Camera has a M64282FP) to understand the things I couldn't before. You should have received this document alongside M64282FP, M64283FP, M64285FP and M64285K datasheets.

I've tried to explain all of the inner workings, enough to interface the cartridge using custom hardware or software and, of course, enough to emulate it correctly!

# 2 The Game Boy Camera Cartridge

The Game Boy Camera cartridge contains 4 ICs: the usual ROM and RAM ICs, a big controller IC (like a MBC) and a sensor (M64282FP "retina" chip).

The main board contains all ICs except from the sensor. From GBDev wiki:

Component#	Part#/inscription	Description
U1	MAC-GBD Nintendo 9807 SA	I/O, memory control.
U2	GBD-PCAX-0 F M538011-E - 08 8145507	1MB ROM
U3	52CV1000SF85LL SHARP JAPAN 9805 5 0A	128KB RAM

The U1 is the only one connected to the GB cartridge pins (besides some of the address pins of the ROM IC). The U2 and U3 (ROM and RAM) are connected to U1. The M64282FP "retina" chip is in a separate PCB, and is connected to the U1.

The M64282FP handles most of the configuration of the capturing process. The U1 transforms the commands from the Game Boy CPU into the correct signals needed for the M64282FP. The detailed timings are described below.

It is a good idea to have the datasheet of the M64282FP, but it is very poorly explained, so this document will try to explain everything about it (except from limits like voltage or signal timings). There are datasheets of similar sensors (M64283FP and M64285FP) that can be very useful to understand some things about the sensor of the GB Camera.

# 2.1 Game Boy Camera MBC

The Game Boy Camera controller works pretty much the same as a MBC3.

0000-3FFF - ROM Bank 00 (Read Only)

First 16 KB of the ROM.

4000-7FFF - ROM Bank 01-3F (Read Only)

This area may contain any ROM bank (0 included). The initial mapped bank is 01.

A000-BFFF - RAM Bank 00-0F (Read/Write)

A000-BFFF - CAM Registers (Read/Write)

Depending on the current RAM Bank Number, this memory space is used to access the cartridge RAM or the CAM registers. RAM can only be read if the capture unit is not working, it returns 00h otherwise.

#### 0000-1FFF - RAM Enable (Write Only)

A value of 0Ah will enable writing to RAM, 00h will disable it. Reading from RAM or registers is always enabled. Writing to registers is always enabled. Disabled on reset.

#### 2000-3FFF - ROM Bank Number (Write Only)

Writing a value of 00-3Fh selects the corresponding ROM Bank for area 4000-7FFF.

#### 4000-5FFF - RAM Bank Number/CAM Registers Select (Write Only)

Writing a value in range for 00h-0Fh maps the corresponding external RAM Bank to memory at A000-BFFF. Writing any value with bit 5 set to '1' will select CAM registers. Usually bank 10h is used to select the registers. All registers are mirrored every 80h bytes. RAM bank 0 selected on reset.

IMPORTANT NOTE: Unlike most games, the GB Camera RAM can only be written when PHI pin = '1'. It's an enable signal for the RAM chip. Most cartridge readers and writers can't handle PHI pin so they can't restore a saved backup. It isn't needed to change ROM banks.

# 2.2 Game Boy Camera I/O Registers

The Game Boy Camera I/O registers are mapped to all banks with bit 4 set to '1'. The GB Camera ROM usually changes to bank 16 to use the registers.

There are 3 groups of registers:

- The first group is composed by the trigger register A000. This register starts the capture process and returns the current status (working/capture finished).
- The second group is composed by registers A001-A005, used to configure most parameters of the M64282FP sensor.

• The third group is composed by 48 registers that form a 4×4 matrix. Each element of the matrix is formed by 3 bytes. This matrix is used by the controller for contrast and dithering.

All registers are write-only, except the register A000. The others return 00h when read. The initial values of all registers on reset is 00h.

## **2.2.1 Register A000**

The lower 3 bits of this register can be read and write. The other bits return '0'. Writing any value with bit 0 set to '1' will start the capturing process. Any write with bit 0 set to '0' is a normal write and won't trigger the capture. The value of bits 1 and 2 affects the value written to registers 4, 5 and 6 of the M64282FP, which are used in 1-D filtering mode (effects described in following chapters).

Bit 0 of this register is also used to verify if the capturing process is finished. It returns '1' when the hardware is working and '0' if the capturing process is over.

When the capture process is active all RAM banks will return 00h when read (and writes are ignored), but the register A000 can still be read to know when the transfer is finished.

The capturing process can be stopped by writing a '0' to bit 0. When a '1' is written again it will continue the previous capture process with the old capture parameters, even if the registers are changed in between. If the process is stopped RAM can be read again.

## **2.2.2 Register A001**

This register is mapped to register 1 of M64282FP. It controls the output gain and the edge operation mode.

## 2.2.3 Registers A002, A003

This registers are mapped to registers 2 and 3 of M64282FP. They control the exposure time. Register 2 is the MSB, register 3 is the LSB.

```
u16 exposure_steps = [A003] | ([A002]<<8);
```

## 2.2.4 Register A004

This register is mapped to register 7 of M64282FP. It sets the output voltage reference, the edge enhancement ratio and it can invert the image.

## **2.2.5 Register A005**

This register is mapped to register 0 of M64282FP. It sets the output reference voltage and enables the zero point calibration.

## 2.2.6 Registers A006-A035

Those registers form a 4×4 matrix with 3 bytes per element. They handle dithering and contrast, and they are sorted by rows:

		)	(	
	00	10	20	30
Υ	01	11	21	31
T	02	12	22	32
	03	13	23	33

A006	A007	A008	A009	A00A	A00B	A00C	A00D	A00E	A00F	A010	A011
D00L	D00M	D00H	D10L	D10M	D10H	D20L	D20M	D20H	D30L	D30M	D30H
A012	A013	A014	A015	A016	A017	A018	A019	A01A	A01B	A01C	A01D
D01L	D01M	D01H	D11L	D11M	D11H	D21L	D21M	D21H	D31L	D31M	D31H
A01E	A01F	A020	A021	A022	A023	A024	A025	A026	A027	A028	A029
D02L	D02M	D02H	D12L	D12M	D12H	D22L	D22M	D22H	D32L	D32M	D32H
A02A	A02B	A02C	A02D	A02E	A02F	A030	A031	A032	A033	A034	A035
D03L	D03M	D03H	D13L	D13M	D13H	D23L	D23M	D23H	D33L	D33M	D33H

This values are used for the contrast and dithering effects in the following way for each pixel at position (X,Y):

- The sensor outputs an analog value. This value is compared to the corresponding group of 3 values of the matrix probably using 3 DACs and 3 comparators (clock timings doesn't affect the result when converting from analog to digital, most ADCs would be affected).
- This value is compared to the corresponding group of 3 values of the matrix. To know what group of 3 values to use do (X mod 4) and (Y mod 4).
- The controller performs the following operations:

```
if ( sensor_value < DxyL ) gb_shade = black;
else if ( sensor_value < DxyM ) gb_shade = dark_gray;
else if ( sensor_value < DxyH ) gb_shade = light_gray;
else gb_shade = white;</pre>
```

This means that the minimum value to show a different color than white is 01h. A value of 00h in the 3 values will always show a white screen. A value of FFh in the 3 bytes will always allow some white pixels in a black background.

If two values are the same, the second comparison will be ignored. If the values are reversed (the higher bytes have lower values) that values are ignored. The previous comparisons explain that kind of behaviors.

To disable dithering all groups of 3 values must be the same. Dithering is obtained by doing small variations in the values of each one of the 4×4 groups. Contrast is handled by modifying the distance between values. Max contrast is reached when the three values of each group are the same. In that case the resulting image has only black and white pixels.

The digital-to-analog conversion is not linear in the sense that a signal of 0V doesn't correspond to a digital value of 00h, it's affine: A value of 00h is around 0.8V and a value of FFh is around

4.1V. Note that the sensor has a 5.0V supply. That means that the value range is approximately 3.3V, but it can't be reached by the sensor output. The sensor can only output from approximately 0.9V to 4.0V (by modifying Vref and other configuration values). The previous limits have been determined by extrapolating, since the values are completely linear (if the offset at 00h is ignored).

According to the sensor datasheet the output voltage range is 2.0V peak to peak. The actual range seems to be up to 3.15V depending on the register configurations. That's the range of values that the controller has to convert into 4 Game Boy gray shades.

The following table shows sample values for the matrix registers. The values are used with dithering enabled, to disable it just repeat the upper left values in all the matrix.

Matrix set 1 (high light)

8C A5 CB 8A 9D C0 8C A3 C8 89 9B BE

Matrix set 2 (low light)

91 AF E6 8D A5 D6 90 AC E2 8C A3 D2

										Lo	wes	t co	ntra	st										
80	8F	D0	8B	BF	EΘ	82	9В	D4	8E	СВ	E4		80	94	DC	8F	CA	F6	83	A1	E2	92	D7	FC
87	AF	DB	83	9F	D5	8A	ВВ	DF	86	AB	D9		8A	В8	ED	85	A6	E4	8D	C5	F4	88	ВЗ	ЕВ
81	97	D2	8D	<b>C</b> 7	E3	80	93	D1	8C	С3	E1		82	9D	E0	91	D3	FA	81	98	DE	90	CE	F8
89	В7	DD	85	Α7	D8	88	ВЗ	DC	84	АЗ	D6		8C	C1	F1	87	AF	E9	8B	вс	EF	86	AA	E6
						'																		
82	90	C8	8C	ВА	DC	84	9A	CD	8F	C4	E1		82	95	D2	90	C2	F3	85	Α0	DA	93	CE	FC
89	AC	D5	85	9E	CE	8B	В6	DA	88	A8	D3		8B	ВЗ	E8	86	A4	DD	8F	BE	F0	8A	AF	E5
83	97	СВ	8E	C1	DF	82	93	С9	8D	BD	DD		84	9C	D7	92	CA	F9	83	98	D4	91	C6	F6
8A	ВЗ	D8	87	A5	D2	89	AF	D7	86	A1	D0		8D	ВВ	EE	89	AB	E2	8C	В7	ЕВ	87	A8	E0
84	90	C0	8D	В4	D8	86	99	C6	8F	BD	DE		84	96	CA	91	BD	F1	87	9F	D3	94	C6	FB
8A	A8	D0	87	9C	C8	8C	В1	D6	89	A5	CE		8D	В0	E4	88	АЗ	D7	90	В9	EE	8B	AC	E1
85	96	C4	8E	ВА	DC	84	93	C2	8D	В7	DA		86	9C	D0	93	С3	F8	85	99	CD	92	C0	F5
8B	ΑE	D4	88	A2	СС	8A	AB	D2	87	9F	CA		8F	В6	EB	8A	Α9	DD	8E	ВЗ	E7	89	A6	DA
85	91	В8	8E	ΑE	D3	87	98	BE	90	В5	DA		86	96	C4	92	В8	F0	89	9E	CF	95	C1	FB
8B	A4	CA	88	9A	C1	8D	AB	D1	8A	A2	С8		8E	AD	E1	8A	A1	D2	91	В5	EC	8D	AA	DD
86	95	вс	8F	ВЗ	D8	85	93	ВА	8E	В0	D6		88	9В	СВ	94	BE	F7	87	98	<b>C7</b>	93	ВВ	F3
8C	Α9	CF	89	9F	C5	8B	A6	СС	88	9D	СЗ		90	В2	E8	8C	Α7	DA	8F	AF	E5	8B	A4	D6
86	91	В1	8E	Α9	D0	88	97	В8	90	AF	D8		88	97	BE	93	В4	EE	8A	9E	CA	96	ВВ	FA
8B	A1	С6	88	99	ВВ	8D	Α7	CD	8A	9F	СЗ		8F	AA	DE	8B	Α0	CE	92	B1	EA	8E	A8	DA
87	95	В6	8F	AD	D5	86	93	ВЗ	8E	AB	D3		89	9В	С6	95	В9	F6	88	99	C2	94	В6	F2

87 92 AA																									
88 95 AF 90 A7 D2 87 93 AC 8F A5 CF 8D A1 C6 8B 9B 8B 8D 9F C3 8A 99 B8  88 92 A5 8F A0 C9 89 95 AE 91 A3 D2 8B 9B A0 A1 CC 8E 9D C3 8B 9B A1 8E 9F C6 8C 9A BA 8B 99 AT 8D 9C C0 8B 97 B1 A1 CF 8D 9A BA 8B 99 B7 8D 9C C0 8B 97 B4  89 92 A2 8F 9E C6 8A 95 AB 91 A1 CF 8D 9A BA 8B 96 A6 AE 8F 9D C3 8C 99 B7 B1 A1 CF 8D 9A BA 8B 96 A6 AE 8F 9D C3 8C 99 B7 B1 A1 CF 8D 9A BA 8B 96 A6 8E 9D C3 8B 9B B1 A1 A0 CF 8D 9A BA 8B 96 A6 8F 9B A0 BB 97 B1  8A 92 A1 99 9D BE 8B 9A A8 91 A0 CF 8B 97 B1  8A 92 A1 99 9D BE 8B 9A A8 91 A0 CF 8B 97 B1  8A 92 A1 99 9D BE 8B 9A A8 91 A0 CF 8B 93 A5 90 BE 9A B1 A0 CF 8B 93 A5 91 9F C7 A7 B1 B2 9A B6 BC 95 A7 B1 B2 9A B6 BC 96 A0 BF 9B B3 A7 B9 B6 B1 B1 A0 CF B1	87	92	AA	8F	Α4	СС	89	96	В2	91	<b>A8</b>	D5		8A	97	В8	93	AF	ED	8C	9D	C5	96	В5	FA
88 92 A5 8F A0 C9 89 95 AE 91 A3 D2 8B 8D 9F C3 8A 99 B8 89 95 AE 91 A3 D2 8D 8B BD 8A 96 B1 8E 9F C6 8C 9A BA 96 B1 8E 9F C6 8C 9A BA 96 AB 97 AB 96 AB 97 AB 96 AB 97 AB 96 AB 97 AB 98 AB 99 AB 8B 98 AB	8C	9E	C1	89	98	В5	8E	A2	С9	8B	9C	BE		90	Α7	DB	8D	9F	С9	92	AD	E8	8F	A5	D7
88 92 A5 8F A0 C9 89 95 AE 91 A3 D2 89 94 AB 90 A2 CF 88 93 A8 90 A1 CC 89 90 C3 88 99 F 8D 9C C0 8B 97 AB 97 AB 89 92 A2 8F 9E C6 8A 95 AB 91 A1 CF 8D 9A BA 88 96 AE BF 9D C3 8C 99 B7 8A 94 AB 90 A2 CB 88 93 A5 91 A1 CF 8D 9A BA 88 96 AE BF 9D C3 8C 99 B7 8A 94 AB 90 A2 CB 88 93 A5 91 A1 CF 8D 9A BA 88 96 AE BF 9D C3 8C 99 B7 8A 94 AB 90 A2 CB 88 93 A5 90 9F C9 8E 9C C0 8C 98 B4 8E 9B BD 8B 97 B1  8A 92 A1 90 9D BE 8B 94 A8 91 A0 C5 8E 9B BA 96 AE BF 9E C6 8A 95 AB 91 A1 CF 8B 9B B9 8D 97 AF 8E 9A B6 8C 96 AD 8B 9B A6 8F 9A B2 8D 97 AB 8E 99 B0 8D 8B 9A B2 8B 9B A8 8B A4 CB 8F 9B B3 9F A1  8B 9B A8 8B B2 94 AB E4 8D 9C BE 97 B0 9A AB 8F A0 C6 8C 9B BA 96 AE C 8B 99 B6 95 AD E8 8C 9B BA 96 AE C 8B 99 B6 95 AD E8 8C 9B BA 96 AE C 8B 99 B6 95 AD E8 8C 9B BA 96 AE C 8B 99 B6 95 AD E8 8C 9B BA 96 AE C 8B 99 B6 95 AD E8 8C 9B BA 96 AE C 8B 99 B6 95 AD E8 8C 9B BA 96 AE C 8B 99 B6 95 AD E8 8C 9B BA 96 AE C 8B 99 B6 95 AD E8 8C 9B BA 96 AE C 8B 99 B6 95 AD E8 8C 9B BA 96 AE C 8B 99 B6 95 AD E8 8C 98 BA 96 AE C 8B 99 B6 95 AD E8 8C 98 BA 96 AE C 8B 99 B6 95 AD E8 8C 98 BA 96 AE C 98 BA 7 C B 8E 98 B7 97 AA E7 92 A2 CB 8F 9D BB 9B 4 A5 D7 91 A0 C7 8D 9A B3 96 A9 9F C3 98 B4 8E 98 BD 8B 97 B1  8A 92 A1 90 9D BE 8B 94 A8 91 A0 C5 8C 98 BA 96 AC 95 A7 D8 8E 9B B7 97 AA E7 92 A2 CB 8F 9D BB 94 A5 D7 91 A0 C7 8D 9A B3 96 A9 F 03 BB 97 AB BE 91 P8 A8 B9 A8 B9 97 B1  8B 92 A1 90 9D BE 8B 94 A8 91 A0 C5 8B 9A A9 90 9F C3 98 A4 BB 91 A1 CF 8D 9A B3 96 A9 BC 96 A6 BF 98 AA B9 A9 B6 B2 8B 93 A3 59 19 F C3 8A 92 A3 90 9E C0 8B 9A BA 95 A5 D8 BF 9B B3 97 A7 BB B9 8B 9B A7 A7 B8 B9 B8 B4 8E 98 B0 8B 98 B2 8B 92 A0 90 9C B6 8C 94 A5 91 9F BC 8B 99 AF 8C 95 A7 B8 8B 99 B0 BD 8B 8B 93 A3 91 9E BB B4 8E 98 BA 8B 98 A1 BB 91 9D B4  8B 92 A0 90 9C B6 8C 94 A5 91 9F B8 8B 93 A3 91 9E BA 8B 89 A1 BB 91 9D B4  8C 92 9E 90 9B AE 8D 94 A2 81 90 9B AF 8C 93 A0 91 9C B8 BB A8 B9 A1 BB 91 9B AB 8C 94 A0 96 96 A0 BF 98 A8 BD 93 A7 BP A7 A7 A7 A7 A7 A7 A7 A8 B9 98 B4 B8 A8 B9 A8 B9 A8 B8 A8 B9 A8	88	95	AF	90	Α7	D2	87	93	AC	8F	A5	CF		8B	9B	C0	95	ВЗ	F6	8A	99	вс	94	B1	F1
B	8D	A1	C6	8B	9В	ВВ	8D	9F	СЗ	8A	99	В8		92	AB	E4	8E	АЗ	D2	91	Α9	DF	8E	A1	CE
B													'				•						•		
89 94 AB 90 A2 CF 88 93 AB 90 A1 CC 8E 9D C3 8B 99 B7 8D 9C CO 8B 97 B4  Default contrast  89 92 A2 8F 9E C6 8A 95 AB 91 A1 CF 8D 9A BA 8B 96 AE 8F 9D C3 8C 99 B7 B4 9C CO 8C 89 93 A5 90 9F C9 BE 9C CO 8C 98 B4 8E 9B BD 8B 97 B1  80 92 A1 90 9D BE 8B 94 A8 91 A0 C5 8E 99 B4 8C 95 AA 8F 9C BB 8D 9B B9 BD 8B 9B BD 8B 9B A5 91 PF C3 8A 92 A3 90 9E CO 8B 93 A5 91 9F C3 8A 92 A3 90 9E CO 8B 9B A5 8C 96 AD  80 92 A0 90 9C B6 8C 94 A5 91 9F BC 8E 99 A7 8B 8B 99 AD 8B 8B 93 A3 91 9E BA 8B 92 A1 90 9D BB B4 8C 95 A7 BF 9B B4 8E 9B BA 8B 92 A1 90 9D B8 BF 9A A3 8D 95 A3 90 9A AD 8E 97 A7 BC 93 A0 91 9C B1 8C 92 9F 90 9B AB 8C 92 PF 90 9B AF 8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4  80 92 9C 90 99 A8 8D 93 A7 8F 96 A3 8D 93 A2 8D 99 A3 8D 93 A3 8D 95 A3 8D 93 A3 8D 95 A3 8D 93 A3 8D 95 A3 8D 95 A3 8D 95 A3 8D 95 A4 8D 95 A4  80 92 9C 90 99 A8 8D 93 A7 8F 96 A3 8D 93 A2 B5 95 A2 BF 97 A5 8E 95 A1  80 99 A6 A6 8F 94 9D 90 98 A1 8F 95 9F B1 93 A2 B5 95 A2 BF 97 A6 B6 95 A2 BF 97 A5 8E 95 A1  80 99 A6 A6 8F 94 9D 90 98 A1 8F 95 9F B1 93 A3 P1 9F AF 92 98 A3 2C 99 A1 99 A4 97 A0 B9 90 99 A3 B2 91 99 A3 8E 92 9B 91 99 A3 BE 93 P1 99 A3 BE 93 P1	88	92	A5	8F	Α0	С9	89	95	ΑE	91	АЗ	D2		8B	98	В2	94	AB	E4	8D	9C	BE	97	В0	F0
BE 9D C3 8B 99 B7 8D 9C C0 8B 97 B4  Default  Default  B9 92 A2 8F 9E C6 8A 95 AB 91 A1 CF  BD 9A BA 8B 96 AE 8F 9D C3 8C 99 B7  BA 94 A8 90 A0 CC 89 93 A5 90 9F C9  BE 9C C0 8C 98 B4 8E 9B BD 8B 97 B1  BA 92 A1 90 9D BE 8B 94 A8 91 A0 C5  BE 99 B4 8C 95 AA 8F 9C BB 8D 98 B2  BB 93 A5 91 9F C3 8A 92 A3 90 9E C0  BF 9B B9 8D 9A F 8C 95 A7 8F 9B B4 8E 9B B0 8C 96 AD  BB 93 A3 91 9E BA 8B 92 A1 90 9D BB B8 92 A1 96 9B B8 93 A3 91 9E BA 8B 92 A1 90 9D BB B8 93 A3 91 9E BA 8B 92 A1 90 9D BB 8B 93 A3 91 9E BA 8B 92 A1 90 9D BB 8B 93 A3 91 9E BA 8B 92 A1 96 9B BA 8B 93 A3 91 9E BA 8B 93 A3 8D 95 A3 90 9A AD 8E 97 A7 BC 93 A0 91 9C B1 8C 92 9F 90 9B AF 8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4  BD 92 9C 90 99 9A 8B D9 3A 7 8F 96 A3 8D 93 A4 8D 93 A4 8D 95 A4 8D 95 A4 8B 95 A4 8D 93 A9 B1 9B AA 8D 93 A4 8D 93 A4 BD 9	8D	9В	BD	8A	96	B1	8E	9F	C6	8C	9A	ВА		91	A5	D3	8E	9E	C2	93	Α9	E0	90	А3	CF
Default contrast  89 92 A2 8F 9E C6 8A 95 AB 91 A1 CF 8D 9A BA 8B 96 AE 8F 9D C3 8C 99 B7 8A 94 A8 90 A0 CC 89 93 A5 90 9F C9 8E 9C C0 8C 98 B4 8E 9B BD 8B 97 B1  8A 92 A1 90 9D BE 8B 94 A8 91 A0 C5 8E 99 B4 8C 95 AA 8F 9C BB 8D 98 B2 8B 93 A5 91 9F C3 8A 92 A3 90 9E C0 8F 9B B9 8D 97 AF 8E 9A B6 8C 96 AD  8B 92 A0 90 9C B6 8C 94 A5 91 9F BC 8B 93 A3 91 9E BA 8B 92 A1 90 9D B8 8B 93 A3 91 9E BA 8B 99 BO 8D 96 A9  8C 92 9E 90 9B AE 8D 94 A2 91 9D B2 8F 98 A9 B9 B9 B0 BD 95 A3 B0 9A AD BE 97 A7 8C 93 A0 91 9C B1 8C 92 9F 90 9B AF 8C 93 A0 91 9C B1 8C 92 9F 90 9B AF 8C 93 A0 91 9C B1 8C 92 9F 90 9B AF 8B 99 A8 8E 96 A6 8F 98 AA 8D 95 A4 8B 99 A8 8E 96 A6 8F 98 AA 8D 95 A4 8B 99 A9 A9 BA BB 99 A9 96 A4 C0 8F 98 A7 96 A3 B8 8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A0 B3 93 9D AD 90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1  8C 92 9B 91 98 A2 8E 93 9C 91 91 9A A4 90 99 A3 9C AC 94 9E B0 92 9B AA 8B 99 A9 A3 9C AC 94 9E B0 92 9B AA 8B 99 A9 A3 9C AC 94 9E B0 92 9B AA 8B 99 A9 A3 9C AC 94 9E B0 92 9B AA 8B 99 A9 B0 A3 97 9F AF 92 98 A2 96 9F AE	89	94	ΑВ	90	A2	CF	88	93	A8	90	A1	СС		8C	9B	ВА	96	ΑE	EC	8B	99	В6	95	AD	E8
88   92   A2   8F   9E   C6   8A   95   AB   91   A1   CF   8D   9A   BA   8B   96   AE   8F   9D   C3   8C   99   B7   8D   9A   A8   90   A0   CC   89   93   A5   90   9F   C9   8E   9C   C0   8C   9B   BA   8E   9B   BD   8B   9F   B1   B1   B2   B2   B3   B4   A5   D7   91   A0   C7   B4   A8   90   A0   CC   89   93   A5   90   9F   C9   B2   B4   B2   9B   BD   8B   97   B1   B3   96   A9   E3   8C   99   AF   95   A8   DF   BE   B2   B2   B2   B2   B3   B4   B3   96   A9   E3   8C   99   AF   95   A8   DF   B2   B3   97   A8   DF   B2   A3   A5   B1   B1   B2   A3   B2   B3   B2   A3   B1   B2   B3   B3   B3   B3   B3   B3   B3	8E	9D	СЗ	8B	99	В7	8D	9C	C0	8B	97	В4		93	A8	DB	8F	A1	СВ	92	A6	D7	8F	Α0	C6
8D 9A BA 8B 96 AE 8F 9D C3 8C 99 B7   8D 9A BA 8B 96 AE 8F 9D C3 8C 99 B7   8D 9A BA 96 AC C8 89 93 A5 90 9F C9   8D 9A BB 9A BB 9A A5 D7 91 A0 C7   8D 9A BB 9A BB 9A A5 D7 9F A6 DF   8D 9A BB 9A BB 9A A6 D7 9B BB 9A A7 BF 9B BB BB 8B 9A A7 BF 9B BB											Def	fau]	t co	ntra	ast										
8A 94 A8         90 A0 CC         89 93 A5         90 9F C9           8E 9C C0         8C 98 B4         8E 9B BD         8B 97 B1           8A 92 A1         90 9D BE         8B 94 A8         91 A0 C5           8E 99 B4 8C 95 AA         8F 9C BB         8D 98 B2           8B 93 A5 91 9F C3         8A 92 A3 90 9E C0           8B 93 A5 91 9F C3         8A 92 A3 90 9E C0           8F 9B B9 BD 97 AF 8E 9A B6 8C 96 AD         8C 96 AD           8B 92 A0 90 9C B6 8C 94 A5 91 9F BC           8B 93 A3 91 9E BA 8B 92 A1 90 9D B8           8B 93 A3 91 9E BA 8B 92 A1 90 9D B8           8B 93 A3 91 9E BA 8B 92 A1 90 9D B8           8B 93 A3 91 9E BA 8B 92 A1 90 9D B8           8B 93 A3 91 9E BA 8B 92 A1 90 9D B8           8B 93 A3 91 9E BA 8B 92 A1 90 9D BB           8B 93 A3 91 9E BA 8B 92 A1 90 9D BB           8B 93 A3 91 9E BA 8B 92 A1 90 9D BB           8B 93 A3 91 9E BA 8B 92 A1 90 9D BB           8B 93 A3 91 9E BA 8B 92 A1 90 9D BB           8B 93 A3 91 9E BA 8B 92 A1 90 9D BB           8B 93 A3 91 9E BA 8B 92 A1 90 9D BA           8B 93 A3 91 9E BA 8B 92 A1 8B 93 BA           8B 93 A4 91 9C B1 8C 92 9F 90 9B AF           8B 94 A0 90 9B AE BD 94 A2 91 9D B2           8B 98 A9 BD 95 A3 90 9A AB BC 93 9A AB BC 93 9A AB BC 93 9A AB BC 93 9A AB BC 94 AB	89	92	A2	8F	9E	C6	8A	95	AB	91	A1	CF		80	98	AC	95	Α7	DB	8E	9В	В7	97	AA	E7
8E 9C C0         8C 98 84         8E 9B BD 8B 97 B1         93 A4 D3         90 9F C3         92 A3 CF 8F 9E BF           8A 92 A1 90 9D BE 8B 94 A8 91 A0 C5         8E 99 B4 8C 95 AA 8F 9C BB 8D 98 B2         8D 98 AA 95 A5 D0 8F 9B B3 97 A8 D9         92 A1 C3 8F 9C B6 94 A4 CD 91 9F C0         8B 93 A5 91 9F C3 8A 92 A3 90 9E C0         8E 9A B0 96 A7 D6 8D 99 AD 95 A6 D3           8F 9B B9 8D 97 AF 8E 9A B6 8C 94 A5 91 9F BC         8E 9A B0 96 A7 D6 8D 99 AD 95 A6 D3         8F 9B BA 95 A4 C6 8F 9B AF 97 A7 CD         93 A3 B5 91 9E BD 93 A2 C6 90 9D B9           8B 92 A0 90 9C B6 8C 94 A5 91 9F BC         8E 98 AB 8D 95 A4 BE 98 AD 8B 92 A1 90 9D B8         8F 9A AD 96 A6 CB 8F 9B AF 97 A7 CD         93 A0 BC 90 9C B2 94 A3 C3 92 9F B9           8B 93 A3 91 9E BA 8B 92 A1 90 9D B8         8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9B A6 95 A2 BC 90 9A AB 97 A5 C2           8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7         8C 92 9F 90 9B AE 8C 92 9F 90 9B AF         8F 98 A6 95 A2 BC 90 9A AB 97 A5 C2           8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4         8F 98 AA 8D 95 A4 BA 90 95 A1 BA 92 9E B3           8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4         8F 98 AB 9D 95 A3 9D 9A AD 8E 97 A7           8D 92 9C 90 99 A8 8D 95 A3 8B 93 9F 91 9A AA 8D 95 A4         9F 98 AB 9B 95 A1 BA 92 9F B6 91 9C AF           8D 93 9E 91 9A AA 8D 92 9D 91 9A AA 8D 92 9D 91 9A AA         9F 98 AB 9B 97 A2 BF 97 A5 BE 95 A1           8D 93 9E 91 9A A6 8E 95 A2 8F 97 A5 8E 95 A1         9F 98 A1 96 9E AD 93 9A 9F A1 B5	8D	9A	ВА	8B	96	ΑE	8F	9D	СЗ	8C	99	В7		92	A2	СВ	8F	9D	ВВ	94	A5	D7	91	Α0	<b>C7</b>
8A 92 A1 90 9D BE 8B 94 A8 91 A0 C5	8A	94	A8	90	Α0	СС	89	93	A5	90	9F	С9		8D	9A	вз	96	Α9	E3	8C	99	AF	95	A8	DF
8E 99 84 8C 95 AA         8F 9C 8B 8D 98 B2           8B 93 A5 91 9F C3 8A 92 A3 90 9E C0           8F 9B B9 8D 97 AF 8E 9A B6 8C 96 AD           8B 92 A0 90 9C B6 8C 94 A5 91 9F BC           8E 99 AF 8C 95 A7 8F 9B B4 8E 98 AD           8B 93 A3 91 9E BA 8B 92 A1 90 9D B8           8F 9B A9 8D 97 AB 8E 99 B0 8D 96 A9           8C 92 9E 90 9B AE 8D 94 A2 91 9D B2           8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4           8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4           8F 99 AB 8E 91 9A AA 8D 95 A4           8F 99 AB 8E 95 A2 8F 97 A5 8E 95 A1           8F 99 AB 8E 95 A4 B6 8C 94 A5 91 9F BC           8F 9A B2 8D 97 AB 8E 9B B4 8E 98 AD           8F 9A B2 8D 97 AB 8E 99 B0 8D 96 A9           8F 9A B2 8D 97 AB 8E 99 B0 8D 96 A9           8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7           8C 92 9E 90 9B AE 8D 94 A2 91 9D B2           8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7           8C 93 A0 91 9C B1 8C 92 9F 90 9B AF 8F 96 A3           8F 99 AB 8E 96 A6 8F 98 AA 8D 93 9F 91 9B AB           8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3           8D 93 9E 91 9A AA 8D 92 9D 91 9A A9           90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1           90 98 A6 9F 9A 99 9A 9B	8E	9C	C0	8C	98	В4	8E	9В	BD	8B	97	В1		93	Α4	D3	90	9F	СЗ	92	АЗ	CF	8F	9E	BF
8E 99 84 8C 95 AA         8F 9C 8B 8D 98 B2           8B 93 A5 91 9F C3 8A 92 A3 90 9E C0           8F 9B B9 8D 97 AF 8E 9A B6 8C 96 AD           8B 92 A0 90 9C B6 8C 94 A5 91 9F BC           8E 99 AF 8C 95 A7 8F 9B B4 8E 98 AD           8B 93 A3 91 9E BA 8B 92 A1 90 9D B8           8F 9B A9 8D 97 AB 8E 99 B0 8D 96 A9           8C 92 9E 90 9B AE 8D 94 A2 91 9D B2           8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4           8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4           8F 99 AB 8E 91 9A AA 8D 95 A4           8F 99 AB 8E 95 A2 8F 97 A5 8E 95 A1           8F 99 AB 8E 95 A4 B6 8C 94 A5 91 9F BC           8F 9A B2 8D 97 AB 8E 9B B4 8E 98 AD           8F 9A B2 8D 97 AB 8E 99 B0 8D 96 A9           8F 9A B2 8D 97 AB 8E 99 B0 8D 96 A9           8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7           8C 92 9E 90 9B AE 8D 94 A2 91 9D B2           8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7           8C 93 A0 91 9C B1 8C 92 9F 90 9B AF 8F 96 A3           8F 99 AB 8E 96 A6 8F 98 AA 8D 93 9F 91 9B AB           8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3           8D 93 9E 91 9A AA 8D 92 9D 91 9A A9           90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1           90 98 A6 9F 9A 99 9A 9B													'												
8B 93 A5 91 9F C3 8A 92 A3 90 9E C0       8E 9A B0 96 A7 D6 8D 99 AD 95 A6 D3         8F 9B B9 8D 97 AF 8E 9A B6 8C 96 AD       9B B9 8D 97 AF 8E 9A B6 8C 96 AD         8B 92 A0 90 9C B6 8C 94 A5 91 9F BC 8E 99 AF 8C 95 A7 8F 9B B4 8E 98 AD 8B 93 A3 91 9E BA 8B 92 A1 90 9D B8 8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8 8F 9A B2 8D 97 AB 8E 99 B0 8D 96 A9         8C 92 9E 90 9B AE 8D 94 A2 91 9D B2 8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7 8C 93 A0 91 9C B1 8C 92 9F 90 9B AF 8F 9A AB 8E 96 A6 8F 98 AA 8D 95 A4         8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4       8F 98 A6 95 A2 BC 90 9A AB 97 A5 C2 9B B3 8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4         8D 92 9C 90 99 A8 8D 93 9F 91 9B AB 8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3 8D 93 9E 91 9A AA 8D 92 9D 91 9A A9 90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1         8D 92 9B 91 98 A2 8E 93 9C 91 9A AB 8B 93 9C 91 9A A4 8B 93 9C 91 9A A4 8B 94 9D 90 9B AF 8B 91 9B AB 8B 94 9D 90 9B A1 8F 95 9F B1 93 9A A5 96 9E AC 94 9B A8 8B 93 9C 91 99 A3 8E 92 9B 91 99 A3 8E 92 9B 91 99 A5 8E 95 AF AF 96 A5 BE 95 AF B1 93 9C A5 PF AF 92 9B A2 96 PF AF B2 8B A2 8B A3 8B A4 8B A4 8B A4 8B A4 8B A4 8B A4 A5 B4 A4 B4 A4 B4 A4 B4 A4 B4	8A	92	A1	90	9D	BE	8B	94	A8	91	Α0	C5		8D	98	AA	95	A5	D0	8F	9В	ВЗ	97	A8	D9
8F 9B B9 8D 97 AF 8E 9A B6 8C 96 AD       93 A3 C9 91 9E BD 93 A2 C6 90 9D B9         8B 92 A0 90 9C B6 8C 94 A5 91 9F BC 8E 99 AF 8C 95 A7 8F 9B B4 8E 98 AD 8B 93 A3 91 9E BA 8B 92 A1 90 9D B8 8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8 94 A2 C1 91 9E B7 93 A1 BE 91 9D B4         8C 92 9E 90 9B AE 8D 94 A2 91 9D B2 8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7 8C 93 A0 91 9C B1 8C 92 9F 90 9B AF 8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4       8F 9A BD 95 A2 BC 90 9A BB 97 A5 C2 93 PF B9 PF	8E	99	В4	8C	95	AA	8F	9C	ВВ	8D	98	B2		92	A1	С3	8F	9C	В6	94	A4	CD	91	9F	C0
8B 92 A0 90 9C B6 8C 94 A5 91 9F BC       8E 98 A8 95 A4 C6 8F 9B AF 97 A7 CD         8E 99 AF 8C 95 A7 8F 9B B4 8E 98 AD       9B 9A 8B 93 A3 91 9E BA 8B 92 A1 90 9D B8         8F 9A B2 8D 97 AB 8E 99 B0 8D 96 A9       8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9A B2 8D 97 AB 8E 99 B0 8D 96 A9       8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9B AF 9A B2 8D 97 AB 8E 99 B0 8D 96 A9       8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9B AF 9A B2 8D 95 A3 90 9A AD 8E 97 A7       8F 9B AF 97 A7         8C 93 A0 91 9C B1 8C 92 9F 90 9B AF       9B AF 99 AB 8E 96 A6 8F 98 AA 8D 95 A4         8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4       9B AB 8D 93 9F 91 9B AB         8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3       9B AB 91 9A AA 8D 92 9D 91 9A A9         90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1            8E 92 9B 91 98 A2 8E 93 9C 91 9A A4 8B 94 9D 90 98 A1 8F 95 9F         8E 92 9B 91 99 A3 8E 92 9B 91 99 A3 8E 92 9B 91 99 A3	8B	93	A5	91	9F	СЗ	8A	92	АЗ	90	9E	C0		8E	9A	В0	96	Α7	D6	8D	99	AD	95	A6	D3
8E 99 AF 8C 95 A7 8F 9B B4 8E 98 AD       93 A0 BC 90 9C B2 94 A3 C3 92 9F B9         8B 93 A3 91 9E BA 8B 92 A1 90 9D B8         8F 9A B2 8D 97 AB 8E 99 B0 8D 96 A9         8C 92 9E 90 9B AE 8D 94 A2 91 9D B2         8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7         8C 93 A0 91 9C B1 8C 92 9F 90 9B AF         8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4         8D 92 9C 90 99 A8 8D 93 9F 91 9B AB         8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3         8D 93 9E 91 9A AA 8D 92 9D 91 9A A9         90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1            90 98 A6 8E 93 91 98 A2 8E 93 9C 91 9A A4         90 96 A0 8F 94 9D 90 98 A1 8F 95 9F         8E 93 9C 91 99 A3 8E 92 9B 91 99 A3 8E 92 9B 91 99 A3	8F	9В	В9	8D	97	AF	8E	9A	В6	8C	96	AD		93	А3	С9	91	9E	BD	93	A2	С6	90	9D	В9
8E 99 AF 8C 95 A7 8F 9B B4 8E 98 AD       93 A0 BC 90 9C B2 94 A3 C3 92 9F B9         8B 93 A3 91 9E BA 8B 92 A1 90 9D B8         8F 9A B2 8D 97 AB 8E 99 B0 8D 96 A9         8C 92 9E 90 9B AE 8D 94 A2 91 9D B2         8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7         8C 93 A0 91 9C B1 8C 92 9F 90 9B AF         8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4         8D 92 9C 90 99 A8 8D 93 9F 91 9B AB         8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3         8D 93 9E 91 9A AA 8D 92 9D 91 9A A9         90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1            90 98 A6 8E 93 91 98 A2 8E 93 9C 91 9A A4         90 96 A0 8F 94 9D 90 98 A1 8F 95 9F         8E 93 9C 91 99 A3 8E 92 9B 91 99 A3 8E 92 9B 91 99 A3																									
8B 93 A3       91 9E BA       8B 92 A1 90 9D B8         8F 9A AD       96 A6 CB       8E 99 AA 96 A5 C8         94 A2 C1 91 9E B7 93 A1 BE 91 9D B4         8C 92 9E 90 9B AE 8D 94 A2 91 9D B2         8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7         8C 93 A0 91 9C B1 8C 92 9F 90 9B AF         8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4         8D 92 9C 90 99 A8 8D 93 9F 91 9B AB         8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3         8D 93 9E 91 9A AA 8D 92 9D 91 9A AB         90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1            8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9A AD 96 A6 CB 8E 99 AA 96 A5 C8         8F 9A AD 96 A6 CB 8E 99 AA 96 A5 BE         9B 9B AF AB 9D 9B AF         8F 98 A6 95 A2 BC 90 9A AB 8D 94 A2 9F 9A 9B AF         9B 9B AF BB 91 9B AB 8B 91 9A AB 8D 95 A1 8B 91 9B AB         9B 9B AF BB 91 9B AB 8B 91 9A AB 8D 92 9B 91 9A AB 95 A1 8B 91 9B AB         9B 9B AF BB 91 9B AB 8B 91 9B AB 8B 92 9B 91 9A AB 8D 93 9B A4 9F AB 91 9B AB         9B 9B 91 9B AB 8B 91 9B AB 8B 92 9B 91 9B AB AB 8B 92 9B 91 9B AB 8B 92 9B AB 8B 92 9B AB 8B	8B	92	Α0	90	9C	В6	8C	94	A5	91	9F	вс		8E	98	A8	95	A4	C6	8F	9В	AF	97	A7	CD
8F 9A 82       8D 97 AB 8E 99 B0 8D 96 A9       94 A2 C1 91 9E B7 93 A1 BE 91 9D B4         8C 92 9E 90 9B AE 8D 94 A2 91 9D B2 8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7 8C 93 A0 91 9C B1 8C 92 9F 90 9B AF 8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4       8F 98 A6 95 A2 BC 90 9A AB 97 A5 C2 93 9F B5 91 9B AD 95 A1 BA 92 9E B3 90 99 A9 96 A4 C0 8F 98 A7 96 A3 BE 94 A0 B8 92 9D B1 94 9F B6 91 9C AF         8D 92 9C 90 99 A8 8D 93 9F 91 9B AB 8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3 8D 93 9E 91 9A AA 8D 92 9D 91 9A A9 90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1       90 98 A4 96 A1 B4 91 9A A8 97 A3 B8 94 9E AF 92 9B A9 95 A0 B3 93 9D AD 91 99 A6 97 A2 B7 90 98 A5 96 A1 B5 95 9F B1 93 9C AC 94 9E B0 92 9B AA         8E 92 9B 91 98 A2 8E 93 9C 91 9A A4 90 96 A0 8F 94 9D 90 98 A1 8F 95 9F 8E 93 9C 91 99 A3 8E 92 9B 91 99 A3       91 99 A3 8E 92 9B 91 99 A3 BE 92 9B 91 99 A3	8E	99	AF	8C	95	Α7	8F	9В	В4	8E	98	AD		93	Α0	вс	90	9C	В2	94	АЗ	С3	92	9F	В9
8C 92 9E 90 9B AE 8D 94 A2 91 9D B2         8F 98 A9 8D 95 A3 90 9A AD 8E 97 A7         8C 93 A0 91 9C B1 8C 92 9F 90 9B AF         8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4         8D 92 9C 90 99 A8 8D 93 9F 91 9B AB         8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3         8D 93 9E 91 9A AA 8D 92 9D 91 9A AB         9B 93 9E 91 9A AA 8D 92 9D 91 9A AB         9B 93 9E 91 9A AA 8D 92 9D 91 9A AB         9B 93 9E 91 9A AA 8D 92 9D 91 9A AB         9B 93 9E 91 9A AA 8D 92 9D 91 9A AB         9B 94 95 A2 8F 97 A5 8E 95 A1            9B 95 A2 BC 90 9A AB 97 A5 C2         93 9F B5 91 9B AD 95 A1 BA 92 9E B3         90 99 A9 96 A4 C0 8F 98 A7 96 A3 BE         90 98 A4 96 A1 B4 91 9A A8 97 A3 B8         94 96 A4 B4 91 9A A8 97 A3 B8         95 9F B1 93 9C AC 94 9E B0 92 9B AA         86 92 9B 91 98 A2 8E 93 9C 91 9A A4         90 98 A4 96 A1 B4 91 9A A8 97 A3 B8         94 96 A4 9B AB 95 A2 BC 9A 9B AB 95 A0 B3 9A A5 96 9E AC 9A 9B AB         95 9C A9 93 9A A5 96 9E AC 9A 9B AB         90 98 A6 8F 9A 9D 9A 8B 9B 9B 9B 9B 9B 9B AB	8B	93	АЗ	91	9E	ВА	8B	92	A1	90	9D	В8		8F	9A	AD	96	A6	СВ	8E	99	AA	96	A5	C8
8F 98 A9       8D 95 A3       90 9A AD 8E 97 A7         8C 93 A0 91 9C B1       8C 92 9F 90 9B AF         8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4       90 99 A9 96 A4 C0 8F 98 A7 96 A3 BE         90 99 A9 96 A4 C0 8F 98 A7 96 A3 BE         90 99 A9 96 A4 C0 8F 98 A7 96 A3 BE         90 98 A4 96 A1 B4 91 9A A8 97 A3 B8         90 98 A4 96 A1 B4 91 9A A8 97 A3 B8         90 98 A6 8E 94 A0 90 98 A7 8F 96 A3         90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1         90 98 A1 96 A1 B4 91 9A A8 97 A3 B8         91 99 A6 97 A2 B7 90 98 A5 96 A1 B5         92 98 A1 96 9E AD 93 99 A4 97 A0 B0         93 9F B5 91 9B AD 95 A1 BA 92 9E B3         90 98 A4 96 A1 B4 91 9A A8 97 A3 B8         94 96 A4 C0 8F 98 A7 96 A3 BE         96 98 A4 96 A1 B4 91 9A A8 97 A3 B8         94 96 A4 B4 91 9A A8 97 A3 B8         95 9F B1 93 9C AC 94 9E B0 92 9B A4         96 98 A4 96 A1 B4 91 9A A8 97 A3 B8         96 98 A4 96 A1 B4 91 9A A8 97 A3 B8         97 98 A6 97 A2 B7 90 98 A5 96 A1 B5         98 98 A6 8E 95 A2 BF 97 A5 BE 95 A1	8F	9A	В2	8D	97	AB	8E	99	во	8D	96	Α9		94	A2	C1	91	9E	В7	93	A1	BE	91	9D	В4
8F 98 A9       8D 95 A3       90 9A AD 8E 97 A7         8C 93 A0 91 9C B1       8C 92 9F 90 9B AF         8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4       90 99 A9 96 A4 C0 8F 98 A7 96 A3 BE         90 99 A9 96 A4 C0 8F 98 A7 96 A3 BE         90 99 A9 96 A4 C0 8F 98 A7 96 A3 BE         90 98 A4 96 A1 B4 91 9A A8 97 A3 B8         90 98 A4 96 A1 B4 91 9A A8 97 A3 B8         90 98 A6 8E 94 A0 90 98 A7 8F 96 A3         90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1         90 98 A1 96 A1 B4 91 9A A8 97 A3 B8         91 99 A6 97 A2 B7 90 98 A5 96 A1 B5         92 98 A1 96 9E AD 93 99 A4 97 A0 B0         93 9F B5 91 9B AD 95 A1 BA 92 9E B3         90 98 A4 96 A1 B4 91 9A A8 97 A3 B8         94 96 A4 C0 8F 98 A7 96 A3 BE         96 98 A4 96 A1 B4 91 9A A8 97 A3 B8         94 96 A4 B4 91 9A A8 97 A3 B8         95 9F B1 93 9C AC 94 9E B0 92 9B A4         96 98 A4 96 A1 B4 91 9A A8 97 A3 B8         96 98 A4 96 A1 B4 91 9A A8 97 A3 B8         97 98 A6 97 A2 B7 90 98 A5 96 A1 B5         98 98 A6 8E 95 A2 BF 97 A5 BE 95 A1																									
8C 93 A0 91 9C B1 8C 92 9F 90 9B AF         8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4         8D 92 9C 90 99 A8 8D 93 9F 91 9B AB         8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3         8D 93 9E 91 9A AA 8D 92 9D 91 9A A9         90 98 A4 96 A1 B4 91 9A A8 97 A3 B8         94 9E AF 92 9B A9 95 A0 B3 93 9D AD         95 9F B1 93 9C AC 94 9E B0 92 9B AA         8E 92 9B 91 98 A2 8E 93 9C 91 9A A4         90 99 A9 96 A4 C0 8F 98 A7 96 A3 BE         90 98 A4 96 A1 B4 91 9A A8 97 A3 B8         94 9E AF 92 9B A9 95 A0 B3 93 9D AD         95 9F B1 93 9C AC 94 9E B0 92 9B AA	8C	92	9E	90	9В	ΑE	8D	94	A2	91	9D	B2		8F	98	A6	95	A2	ВС	90	9A	AB	97	A5	C2
8F 99 AB 8E 96 A6 8F 98 AA 8D 95 A4       94 A0 B8 92 9D B1 94 9F B6 91 9C AF         8D 92 9C 90 99 A8 8D 93 9F 91 9B AB 8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3 8D 93 9E 91 9A AA 8D 92 9D 91 9A A9 90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1       90 98 A4 96 A1 B4 91 9A A8 97 A3 B8 94 9E AF 92 9B A9 95 A0 B3 93 9D AD 91 9A A9 91 9A AB 95 AD B1 94 9E AF 92 9B AB 95 AD B1 94 9E BD 92 9B AA         8E 92 9B 91 98 A2 8E 93 9C 91 9A A4 90 96 A0 8F 94 9D 90 98 A1 8F 95 9F 8E 93 9C 91 9A A8 8E 92 9B 91 99 A3 8E 92 9B 91 99 A3       91 9A AB 9C AF BB 91 9A AB 9C AF BB 91 9B AB 91 9B AB 92 9B AB 91 9B AB 91 9B AB 92 9B AB 91 9B AB 92 9B AB 91 9B AB 92 9B AB 92 9B AB 91 9B AB 92 9B AB 93 9A AB 96 9E AC 94 9B AB 92 9B AB 93 9A AB 96 9E AC 94 9B AB 93 9A AB 96 9E AC 94 9B AB 93 9A AB 96 9F AE 92 9B AB 92 9B AB 92 9B AB 93 9A AB 96 9F AE 92 9B AB 93 9A AB 96 9F AE 92 9B AB 94 9B AB 95 AB 95 9F AF 92 9B AB 95	8F	98	Α9	8D	95	АЗ	90	9A	AD	8E	97	Α7		93	9F	В5	91	9В	AD	95	A1	ВА	92	9E	ВЗ
8D 92 9C 90 99 A8 8D 93 9F 91 9B AB 8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3 8D 93 9E 91 9A AA 8D 92 9D 91 9A A9 90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1  8E 92 9B 91 98 A2 8E 93 9C 91 9A A4 90 96 A0 8F 94 9D 90 98 A1 8F 95 9F 8E 93 9C 91 99 A3 8E 92 9B 91 99 A3  8D 93 9F B1 93 9C AC 94 9E B0 92 9B AB 90 98 A4 96 A1 B4 91 9A A8 97 A3 B8 91 99 A6 A1 B4 91 9A A8 97 A3 B8 92 98 A1 96 A1 B4 91 9A A8 97 A3 B8 93 95 A0 B3 93 9D AD 95 9F B1 93 9C AC 94 9E B0 92 9B AA  8E 92 9B 91 98 A2 8E 93 9C 91 9A A4 95 9F B1 93 9C AC 94 9E B0 92 9B AB 95 9C A9 93 9A A5 96 9E AC 94 9B AB 95 9C A9 93 9A A5 96 9E AC 94 9B AB 95 9C A9 93 9A A5 96 9F AF	8C	93	Α0	91	9C	B1	8C	92	9F	90	9B	AF		90	99	Α9	96	A4	C0	8F	98	Α7	96	А3	BE
8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3         8D 93 9E 91 9A AA 8D 92 9D 91 9A A9         90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1         94 9E AF 92 9B A9 95 A0 B3 93 9D AD         91 99 A6 97 A2 B7 90 98 A5 96 A1 B5         95 9F B1 93 9C AC 94 9E B0 92 9B AA         8E 92 9B 91 98 A2 8E 93 9C 91 9A A4         90 96 A0 8F 94 9D 90 98 A1 8F 95 9F         8E 93 9C 91 99 A3 8E 92 9B 91 99 A3	8F	99	AB	8E	96	A6	8F	98	AA	8D	95	A4		94	Α0	В8	92	9D	B1	94	9F	В6	91	9C	AF
8F 97 A4 8E 94 A0 90 98 A7 8F 96 A3         8D 93 9E 91 9A AA 8D 92 9D 91 9A A9         90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1         94 9E AF 92 9B A9 95 A0 B3 93 9D AD         91 99 A6 97 A2 B7 90 98 A5 96 A1 B5         95 9F B1 93 9C AC 94 9E B0 92 9B AA         8E 92 9B 91 98 A2 8E 93 9C 91 9A A4         90 96 A0 8F 94 9D 90 98 A1 8F 95 9F         8E 93 9C 91 99 A3 8E 92 9B 91 99 A3																									
8D 93 9E 91 9A AA 8D 92 9D 91 9A A9         90 98 A6 8E 95 A2 8F 97 A5 8E 95 A1         91 99 A6 97 A2 B7 90 98 A5 96 A1 B5         95 9F B1 93 9C AC 94 9E B0 92 9B AA         8E 92 9B 91 98 A2 8E 93 9C 91 9A A4         90 96 A0 8F 94 9D 90 98 A1 8F 95 9F         8E 93 9C 91 99 A3 8E 92 9B 91 99 A3            91 99 A6 97 A2 B7 90 98 A5 96 A1 B5         95 9F B1 93 9C AC 94 9E B0 92 9B AA            92 98 A1 96 9E AD 93 99 A4 97 A0 B0         95 9C A9 93 9A A5 96 9E AC 94 9B A8         92 99 A3 97 9F AF 92 98 A2 96 9F AE	8D	92	9C	90	99	A8	8D	93	9F	91	9B	AB		90	98	A4	96	A1	В4	91	9A	A8	97	А3	В8
90 98 A6       8E 95 A2       8F 97 A5       8E 95 A1       95 9F B1 93 9C AC 94 9E B0 92 9B AA         8E 92 9B 91 98 A2       8E 93 9C 91 9A A4       92 98 A1 96 9E AD 93 99 A4 97 A0 B0 96 A0 8F 94 9D 90 98 A1 8F 95 9F 8F 9C A9 93 9A A5 96 9E AC 94 9B A8 92 99 A3 97 9F AF 92 98 A2 96 9F AE	8F	97	Α4	8E	94	Α0	90	98	Α7	8F	96	АЗ		94	9E	AF	92	9B	Α9	95	Α0	ВЗ	93	9D	AD
8E 92 9B 91 98 A2 8E 93 9C 91 9A A4         90 96 A0 8F 94 9D 90 98 A1 8F 95 9F         8E 93 9C 91 99 A3 8E 92 9B 91 99 A3             92 98 A1 96 9E AD 93 99 A4 97 A0 B0         95 9C A9 93 9A A5 96 9E AC 94 9B A8         92 98 A1 96 9E AD 93 99 A4 97 A0 B0         95 9C A9 93 9A A5 96 9E AC 94 9B A8         92 99 A3 97 9F AF 92 98 A2 96 9F AE	8D	93	9E	91	9A	AA	8D	92	9D	91	9A	Α9		91	99	A6	97	A2	В7	90	98	A5	96	A1	В5
90 96 A0 8F 94 9D 90 98 A1 8F 95 9F 8E 93 9C 91 99 A3 8E 92 9B 91 99 A3 97 9F AF 92 98 A2 96 9F AE	90	98	A6	8E	95	A2	8F	97	A5	8E	95	A1		95	9F	B1	93	9C	AC	94	9E	В0	92	9B	AA
90 96 A0 8F 94 9D 90 98 A1 8F 95 9F 8E 93 9C 91 99 A3 8E 92 9B 91 99 A3 97 9F AF 92 98 A2 96 9F AE													1												
8E 93 9C 91 99 A3 8E 92 9B 91 99 A3 97 9F AF 92 98 A2 96 9F AE	8E	92	9В	91	98	A2	8E	93	9C	91	9A	A4		92	98	A1	96	9E	AD	93	99	A4	97	Α0	В0
	90	96	Α0	8F	94	9D	90	98	A1	8F	95	9F		95	9C	A9	93	9A	A5	96	9E	AC	94	9В	A8
90 97 A1 8F 95 9E 90 97 A0 8F 94 9E 95 9D AB 94 9B A7 95 9D AA 93 9A A6	8E	93	9C	91	99	А3	8E	92	9В	91	99	А3		92	99	А3	97	9F	AF	92	98	A2	96	9F	AE
	90	97	A1	8F	95	9E	90	97	Α0	8F	94	9E		95	9D	AB	94	9B	Α7	95	9D	AA	93	9A	A6

8F	92	99	91	97	9E	8F	93	9A	91	98	9F		94	98	9D	97	9В	Α5	94	98	9F	97	9C	Α7
90	95	9C	8F	93	9A	91	96	9D	90	95	9C		96	9A	A2	95	99	9F	96	9В	A4	95	9A	A1
8F	92	99	91	98	9F	8F	92	99	91	97	9E		94	98	9E	97	9C	A6	94	98	9D	97	9C	A5
90	96	9D	90	94	9В	90	95	9C	8F	94	9В		96	9В	АЗ	95	99	A1	96	9A	АЗ	95	99	Α0
						•						'												
90	92	97	91	95	99	90	92	97	91	96	99		96	98	99	97	98	9E	96	98	9A	97	98	9F
91	94	98	90	93	97	91	95	99	90	94	98		97	98	9C	96	98	9A	97	98	9D	96	98	9C
90	92	97	91	96	99	90	92	97	91	96	99		96	98	99	97	98	9F	96	98	99	97	98	9E
91	95	98	90	93	98	91	94	98	90	93	97		97	98	9D	96	98	9В	97	98	9C	96	98	9В
										Ηiς	ghes	t co	ntra	ast										
92	92	92	92	92	92	92	92	92	92	92	92		98	98	98	98	98	98	98	98	98	98	98	98
92	92	92	92	92	92	92	92	92	92	92	92		98	98	98	98	98	98	98	98	98	98	98	98
92	92	92	92	92	92	92	92	92	92	92	92		98	98	98	98	98	98	98	98	98	98	98	98
92	92	92	92	92	92	92	92	92	92	92	92		98	98	98	98	98	98	98	98	98	98	98	98
												1												

Example with values from set 1 (the output values are the GB shades with 3=black, 0= white):

In (00h-FFh)	0000111122223333444455556666777788889999AAAABBBBCCCCDDDDEEEEFFFF
Min: 80 8F D0	3333333333333333333333333333332222111111
Def: 89 92 A2	333333333333333333333333333333333333333
Max: 92 92 92	33333333333333333333333333333333333330000

# 2.3 Game Boy Camera timings

The capture process is started when the A000 register of the Game Boy Camera cartridge is written any value with bit 0 set to '1'.

The Game Boy Camera cartridge is one of the few cartridges that use the PHI signal (clock from the GB). That signal is a 1MHz clock (1048576 Hz). The M64282FP chip needs a clock input too, which is half the frequency of the PHI pin (0.5 MHz, 524288Hz). The reason for that is that the sensor chip sometimes handles the signals on the rising edge of the clock but other times on the falling edge. NOTE: This means that the GB Camera shouldn't be used in GBC double speed mode!

The time needed to capture and process an image depends on the exposure time and the value of the N bit of the register 1 of the M64282FP chip.

In GAME BOY CYCLES (1MHz):

```
N_bit = ([A001] & BIT(7)) ? 0 : 512
exposure = ([A002]<<8) | [A003]
CYCLES = 32446 + N_bit + 16 * exposure
```

Divide that values by 2 to get the sensor clocks.

## 2.3.1 Capture process timings

The next values are in sensor clocks. Multiply by 2 to get Game Boy cycles.

```
- Reset pulse.
 Configure sensor registers. (11 x 8 CLKs)
 Wait
                                        (1 CLK)
 Start pulse
                                        (1 CLK)
- Exposure time
                      (exposure_steps x 8 CLKs)
 Wait
                                       (2 CLKs)
- Read start
                     (N=1 ? 16128 : 16384 CLKs)
- Read period
- Read end
- Wait
                                       (3 CLKs)
- Reset pulse to stop the sensor
(88 + 1 + 1 + 2 + 16128 + 3 = 16223)
CLKs = 16223 + ( N_bit ? 0 : 256 ) + 8 * exposure
```

Obviously, that's the previous result divided by 2.

During the read process every pixel is written when it is read from the sensor. If the read process is stopped (by shutting the GB down, for example) the RAM will have the contents of the current picture until the read was stopped, from there it will have the data from the image captured before that one. The sensor transfers 128×128 pixels, but the upper and lower rows are corrupted. The Game Boy Camera controller only uses the medium rows of the sensor image. This means that it ignores the first 8 rows and the last 8 rows.

The clock signal during read period must be the same as the one used during the exposure time. If the clock during the read period is too slow the sensor will continue increasing the charge values of each pixel so the image will appear to be taken with a higher exposure time. The brightness doesn't seem to increase always, there seems to be some kind of limit.

# 3 The Game Boy Camera sensor (M64282FP)

The M64282FP does some processing to the captured image. First it performs an edge control, then it does gain control and last it does level control. The resulting analog value is the one that can be read in Vout pin. The sensor can capture infrared radiation, so images can be a bit strange compared to others captured by better sensors.

# 3.1 The M64282FP registers

## 3.1.1 Register 1

This corresponds to the register A001 of the Game Boy Camera. When shooting, the values change based on how much light there is.

Symbol	Bits	Operation
N	7	Exclusively set vertical edge enhancement mode.
VH	5-6	Select vertical/horizontal edge operation mode.
G	0-4	Analog output gain.

G3	G2	<b>G1</b>	G0	Gain
0	0	0	0	14.0
0	0	0	1	15.5
0	0	1	0	17.0
Θ	0	1	1	18.5
Θ	1	0	0	20.0
Θ	1	0	1	21.5
Θ	1	1	0	23.0
Θ	1	1	1	24.5
1	0	0	0	26.0
1	0	0	1	29.0
1	0	1	0	32.0
1	0	1	1	35.0
1	1	0	0	38.0
1	1	0	1	41.0
1	1	1	0	45.5
1	1	1	1	51.5

If G4='1' the total gain is the previous one plus 6dB. The Game Boy Camera uses 00h, 04h, 08h and 0Ah. They are 14.0dB, 20.0dB, 26.0dB and 32dB, which translate to a gain of 5.01, 10.00, 19.95 and 39.81. The Game Boy Camera seems to like to duplicate the gain in each step.

## 3.1.2 Registers 2 and 3

They contain the exposure time (16 bit unsigned value). According to the M64282FP datasheet each step is 16  $\mu$ s. In the GB it needs 16 PHI clocks for every step. If N='1' exposure\_steps should be greater or equal than 0030h.

```
u16 exposure_steps = ([Reg2]<<8) | [Reg3] 
 Step time = 1 / 1048576 Hz * 16 = 0,954 \mu s * 16 = 15,259 \mu s
```

It's a bit less than the 16 µs the datasheet says, but it's close enough. Some example values to get acceptable pictures under various light conditions:

Value	Conditions
0030h	Objects under direct sunlight.
0300h	Objects not under direct sunlight.
0800h	Room during the day with good light.
2C00h	Room at night with light.
5000h	Room at night with no light, only a reading lamp.
F000h	Room at night with only a TV on in the background.

Those values are illustrative, and they are important because the exposure time affects the time that is needed to take a picture. The initial value set by the ROM is 1000h.

## 3.1.3 Registers 4, 5 and 6

They are used by the 1-D processing kernel. They can't be set to any value from the GB Camera cartridge, only to 3 defined sets of values. The value of X must be fixed to 01h according to the datasheet. The values of P and M can't be modified if N='1', they are set to automatic values.

[A000]	[4]=P	[5]=M	[6]=X	Description
1(001)	00h	01h	01h	Negative
3(011)	01h	00h	01h	Positive. This is the value the GB Camera ROM uses.
5(101)	01h	02h	01h	Used for edge detection
7(111)	01h	02h	01h	Used for edge detection

## 3.1.4 Register 7

This corresponds to the register A004 of the Game Boy Camera.

Symbol	Bits	Operation
Е	4-7	Edge enhancement ratio
I	3	Select inverted/non-inverted output
V	0-2	Output node bias voltage (Vref)

E2	E1	E0	Edge Enhancement Ratio		
0	0	0	50%		
0	0	1	75%		
0	1	0	100%		
0	1	1	125%		
1	0	0	200%		
1	0	1	300%		
1	1	0	400%		
1	1	1	500%		

V2	V1	V0	Vref(V)
0	0	0	0.0
0	0	1	0.5
0	1	0	1.0
0	1	1	1.5
1	0	0	2.0
1	0	1	2.5
1	1	0	3.0
1	1	1	3.5

## 3.1.5 Register 0

This corresponds to the register A005 of the Game Boy Camera.

Symbol	Bits	Operation
Z	6-7	Zero point calibration (Set dark level output signal to Vref)
0	0-5	Output reference voltage (In both plus and minus direction)

The two calibration modes that are used are '10' (calibration for positive signal) and '00' (disabled). Note: The undefined Z='11' configuration is the same as Z='00'. The unused configuration Z='01' is used for calibration for negative signal.

The reference voltage is adjusted in 32mV steps, with the most significant bit being the sign (O5='1' is positive). The output reference voltage is calculated like this:

```
int reg_offset = REG[0] & 0x1F;
float offset_step = ( (reg_offset & 0x20) ? 0.032 : -0.032 )
float OFFSET = offset_step * (reg_offset & 0x1F)
```

# 3.2 M64282FP image processing

The image processing is done in three stages: Edge control, gain control and level control. Since the sensor is very badly documented, most of this part is guesswork (specially gain and level control). Anyway, only the edge control is needed to emulate the Game Boy Camera.

```
Original
                         [0V, 5V]
Invert
                         [0V,5V] \
3x3 kernel
                         [0V,5V]
                                 | Edge control
1-D filter
                         [0V,5V] /
Zero calibration
                         [0V,5V] \
                         [0V,5V]
                                 | Gain control
Offset
Gain -> Origin is 2.5 V [OV, 5V] /
Vref
                         [0V,5V] -> Level control
Final clamped output
                        [0.9V, 4.0V]
```

## 3.2.1 Edge control

Note that, before any edge processing, the inverting bit of register 7 is processed. The edge processing type depends on the value of registers N, VH and E. If 1-D filtering is enabled, the registers P, M and X are also used. If N is set to '1' the registers P and M are ignored as they are used by the 3×3 filtering kernel (so changing the value used to trigger the capture doesn't change the resulting image). When using edge extraction modes Z1 should be set to '0'. In any other cases, it should be set to '1'. The 3×3 filtering kernel is applied before the 1-D filtering.

N	VH1	VH0	E3	Description	1-D enabled	3×3 filtering matrix kernel
0	0	0	0	Positive image	Yes	Disabled.
0	0	1	0	Horiz. enhancement	Yes	0 0 0   -1 3 -1   0 0 0
0	0	1	1	Horiz. extraction	Yes	0 0 0   -1 2 -1   0 0 0
1	1	0	0	Vert. enhancement	No	0 -1 0   0 3 0   0 -1 0
1	1	0	1	Vert. extraction	No	0 -1 0   0 2 0   0 -1 0
1	1	1	0	2D enhancement	No	0 -1 0   -1 5 -1   0 -1 0
1	1	1	1	2D extraction	No	0 -1 0   -1 4 -1   0 -1 0

*Table 1: Edge processing modes.* 

Other combinations are undefined and shouldn't be used.

#### • 3×3 filtering matrix kernel

This consists on a  $3\times3$  matrix. The configuration values to use each mode and the resulting values used to calculate the final image are specified in 1. The following expressions are used to calculate the result ( $\alpha$ : edge enhancement ratio), and the images show examples for  $\alpha = 100\%$ :

Edge mode	Operation
Vertical edge extraction	$\{2P-(MN+MS)\} \times \alpha$
Horizontal edge extraction	$\{2P-(MW+ME)\} \times \alpha$
2D edge extraction	$\{4P-(MN+MS+ME+MW)\} \times \alpha$
Vertical edge enhancement	$P + \{2P-(MN+MS)\} \times \alpha$
Horizontal edge enhancement	$P + \{2P-(MW+ME)\} \times \alpha$
2D edge enhancement	$P + \{4P-(MN+MS+ME+MW)\} \times \alpha$

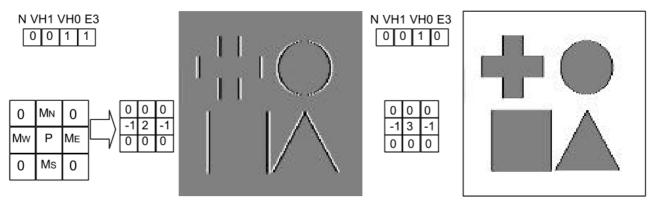


Figure 1: Horizontal edge processing modes.

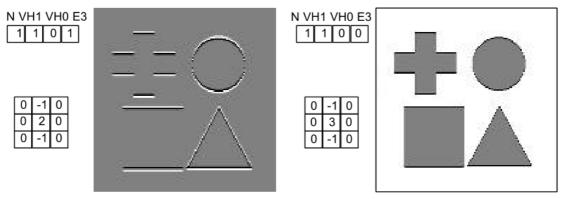


Figure 2: Vertical edge processing modes.

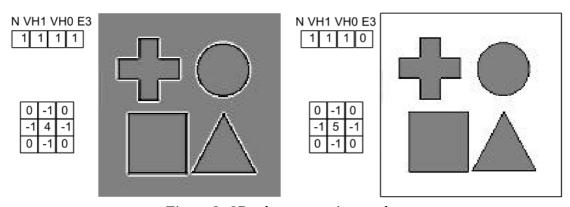


Figure 3: 2D edge processing modes.

## • 1-D filtering mode

When using edge extraction, Z1 should be '0'. It uses the P, M and X registers like this:

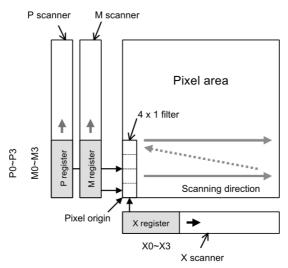
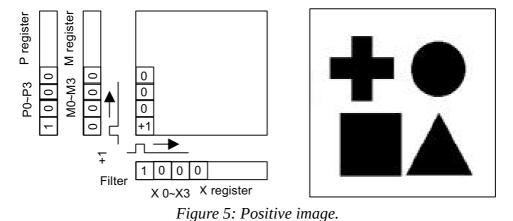


Figure 4: 1-D filtering hardware.

P, M and X are bitmasks. The bits set to '1' select lines of the image. The lines selected in P register (plus?) are added, the ones in M register (minus?) are subtracted. If the 2 bits of the same line are set to '1' the result is the same as if they were '0'. According to the datasheet, the X register must be set to '01h', the Game Boy Camera does it automatically. The three possible configurations depending on the value written to A000 register when triggering the capture are:

[A000]	[4]=P	[5]=M	[6]=X	Description
1(001)	00h	01h	01h	Negative. Figure 6.
3(011)	01h	00h	01h	Positive. Figure 5.
5(101)	01h	02h	01h	Used for edge extraction. Figure 7.
7(111)	01h	02h	01h	Used for edge extraction. Figure 7.

The three following images show how it works:



i igan e sv i estave image

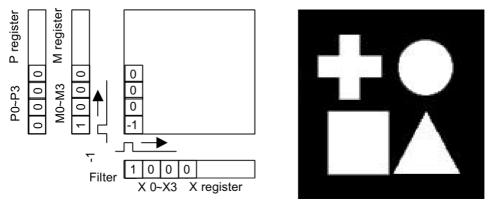


Figure 6: Negative image.

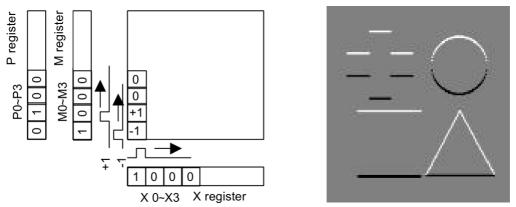


Figure 7: Edge extraction.

## 3.2.2 Gain control

This is not explained properly in the datasheet, so don't trust this information too much. In this phase the zero point calibration is applied (at the beginning?), then the output reference voltage is added and at last the gain is applied.

#### 3.2.3 Level control

Vref is applied and the output is clamped to [0.9V, 4.0V].

# 4 Sample code for emulators

The following code is used to convert a greyscale image to the Game Boy Camera format. GB\_CameraTakePicture() should be called when bit 0 of A000 register is st to '1'. The emulator should wait CAM\_CLOCKS\_LEFT until the bit 0 is cleared. The gain and level control are not needed to emulate the Game Boy Camera because webcams do that automatically. In fact, trying to emulate that will probably break the image. The code is not very clean because it has been extracted from my GiiBiiAdvance, but it seems to handle all used configurations of edge handling.

Note that the actual Game Boy Camera sensor is affected by infrared so the emulation can't be perfect anyway. A good way of converting a RGB image into grayscale is to do:

$$V = (2 \times R + 5 \times G + 1 \times B) / 8$$

```
// The actual sensor image is 128x126 or so. #define GBCAM_SENSOR_EXTRA_LINES (8) #define GBCAM_SENSOR_W (128)
#define GBCAM_SENSOR_H (112+GBCAM_SENSOR_EXTRA_LINES)
#define GBCAM_W (128)
#define GBCAM_H (112)
#define BIT(n) (1<<(n))</pre>
// Webcam image
static int gb_cam_retina_output_buf[GBCAM_SENSOR_W][GBCAM_SENSOR_H];
static inline int clamp(int min, int value, int max)
{
    if(value < min) return min;</pre>
    if(value > max) return max;
    return value:
}
static inline int min(int a, int b) { return (a < b) ? a : b; }</pre>
static inline int max(int a, int b) { return (a > b) ? a : b; }
static inline u32 gb_cam_matrix_process(u32 value, u32 x, u32 y)
    x = x & 3;
    y = y & 3;
    int base = 6 + (y*4 + x) * 3;
    u32 r0 = CAM_REG[base+0];
    u32 r1 = CAM REG[base+1];
    u32 r2 = CAM REG[base+2];
    if(value < r0) return 0x00;</pre>
    else if(value < r1) return 0x40;
else if(value < r2) return 0x80;</pre>
    return 0xC0;
static void GB_CameraTakePicture(void)
    int i, j;
    // Get webcam image
    GB CameraWebcamCapture();
    //-----
    // Get configuration
// -----
    // Register 0
    u32 P bits = 0;
    u32 M bits = 0;
    switch( (CAM_REG[0]>>1)&3 )
{
        case 0: P_bits = 0x00; M_bits = 0x01; break;
case 1: P_bits = 0x01; M_bits = 0x00; break;
        case 2: case 3: P_bits = 0x01; M_bits = 0x02; break;
        default: break;
    }
    // Register 1
u32 N_bit = (CAM_REG[1] & BIT(7)) >> 7;
    u32 VH_bits = (CAM_REG[1] & (BIT(6)|BIT(5))) >> 5;
    // Registers 2 and 3
    u32 EXPOSURE_bits = CAM_REG[3] | (CAM_REG[2]<<8);
```

```
// Register 4
const float edge_ratio_lut[8] = { 0.50, 0.75, 1.00, 1.25, 2.00, 3.00, 4.00, 5.00 };
float EDGE_alpha = edge_ratio_lut[(CAM_REG[4] & 0x70)>>4];
u32 E3 bit = (CAM REG[4] & BIT(7)) >> 7;
u32 I bit = (CAM REG[4] & BIT(3)) \gg 3;
  Calculate timings
CAM CLOCKS LEFT = 4 * (32446 + (N bit ? 0:512) + 16 * EXPOSURE bits);
 / Sensor handling
//Copy webcam buffer to sensor buffer applying color correction
for(i=0;i<gBCAM SENSOR W;i++) for(j=0;j<gBCAM SENSOR H;j++)</pre>
    int value = gb camera webcam output[i][j];
value = 128 + 0.75f*(float)(value-128);
    gb cam retina output buf[i][j] = clamp(0, value, 255);
// Apply exposure time (with a reference of 0x0100)
for(i=0;i<gBCAM SENSOR W;i++) for(j=0;j<gBCAM SENSOR H;j++)</pre>
    int result = gb_cam_retina_output_buf[i][j];
result = ( (result * EXPOSURE_bits ) / 0x0100 );
    gb_cam_retina_output_buf[i][j] = clamp(0, result, 255);
3
if(I bit) // Invert image
    for(i=0;i<GBCAM_SENSOR_W;i++) for(j=0;j<GBCAM_SENSOR_H;j++)
     gb_cam_retina_output_buf[i][j] ^= 255;</pre>
int temp_buf[GBCAM_SENSOR_W][GBCAM_SENSOR_H];
u32 filtering mode = (N \text{ bit} <<3) \mid (VH \text{ bits} <<1) \mid E3 \text{ bit};
switch(filtering_mode)
    case 0x0: // 1-D filtering
{
         for(i=0;i<GBCAM_SENSOR_W;i++) for(j=0;j<GBCAM_SENSOR_H;j++)</pre>
              temp_buf[i][j] = gb_cam_retina_output_buf[i][j];
         for(i=0;i<GBCAM_SENSOR_W;i++) for(j=0;j<GBCAM_SENSOR_H;j++)
              int ms = temp_buf[i][min(j+1,GBCAM_SENSOR_H-1)];
              int px = temp_buf[i][j];
              int value = 0;
              if(P_bits&BIT(0)) value += px;
if(P_bits&BIT(1)) value += ms;
              if(M_bits&BIT(0)) value -= px;
              if(M bits&BIT(1)) value -= ms;
              gb cam retina output buf[i][j] = clamp(0, value, 255);
         break:
    case 0x2: //1-D filtering + Horiz. enhancement : P + \{2P-(MW+ME)\} * alpha
         for(i=0;i<GBCAM_SENSOR_W;i++) for(j=0;j<GBCAM_SENSOR_H;j++)</pre>
              int mw = gb_cam_retina_output_buf[max(0,i-1)][j];
              int me = gb cam_retina_output_buf[min(i+1,GBCAM_SENSOR_W-1)][j];
int px = gb_cam_retina_output_buf[i][j];
              temp buf[i][j] = clamp(0,px+((2*px-mw-me)*EDGE alpha),255);
         for(i=0;i<GBCAM_SENSOR_W;i++) for(j=0;j<GBCAM_SENSOR_H;j++)
              int ms = temp_buf[i][min(j+1,GBCAM_SENSOR_H-1)];
              int px = temp_buf[i][j];
```

```
int value = 0;
              if(P_bits&BIT(0)) value += px;
              if(P_bits&BIT(1)) value += ms;
if(M_bits&BIT(0)) value -= px;
              if(M_bits&BIT(1)) value -= ms;
              gb_cam_retina_output_buf[i][j] = clamp(0,value,255);
         break;
    }
case 0xE: //2D enhancement : P + {4P-(MN+MS+ME+MW)} * alpha
          for(i=0;i<GBCAM_SENSOR_W;i++) for(j=0;j<GBCAM_SENSOR_H;j++)</pre>
              int ms = gb_cam_retina_output_buf[i][min(j+1,GBCAM_SENSOR_H-1)];
int mn = gb_cam_retina_output_buf[i][max(0,j-1)];
              int mw = gb_cam_retina_output_buf[max(0,i-1)][j];
              int me = gb cam retina output buf[min(i+1,GBCAM SENSOR W-1)][j];
              int px = gb_cam_retina_output_buf[i][j];
              temp_buf[i][j] = clamp(0,px+((4*px-mw-me-mn-ms)*EDGE alpha),255);
          for(i=0;i<gbcam_sensor_w;i++) for(j=0;j<gbcam_sensor_h;j++)
              gb_cam_retina_output_buf[i][j] = temp_buf[i][j];
         break:
     case 0x1:
         // In my GB Camera cartridge this is always the same color.
// The datasheet of the sensor doesn't have this configuration
// documented. Maybe this is a bug?
for(i=0;i<GBCAM_SENSOR_W;i++) for(j=0;j<GBCAM_SENSOR_H;j++)</pre>
              gb_cam_retina_output_buf[i][j] = 0x80;
         }
break;
    }
default:
          // Ignore filtering
         printf("Unsupported GB Cam mode: 0x%x\n%02x %02x %02x %02x %02x %02x",
                  filtering mode,
                  CAM REG[0], CAM REG[1], CAM REG[2], CAM REG[3], CAM REG[4], CAM REG[5]);
         break;
    }
}
   Controller handling
int fourcolorsbuffer[GBCAM_W][GBCAM_H]; // buffer after controller matrix
// Convert to Game Boy colors using the controller matrix
for(i = 0; i < GBCAM_W; i++) for(j = 0; j < GBCAM_H; j++)
    fourcolorsbuffer[i][j] =</pre>
         gb_cam_matrix_process(
              gb_cam_retina_output_buf[i][j+(GBCAM_SENSOR_EXTRA_LINES/2)],i,j);
// Convert to tiles
u8 finalbuffer[14][16][16]; // final buffer
memset(finalbuffer,0,sizeof(finalbuffer));
for(i = 0; i < GBCAM_W; i++) for(j = 0; j < GBCAM_H; j++)</pre>
     u8 outcolor = 3 - (fourcolorsbuffer[i][j] >> 6);
     u8 * tile base = finalbuffer[j>>3][i>>3];
    tile_base = &tile_base[(j&7)*2];
     if(outcolor & 1) tile_base[0] |= 1<<(7-(7&i));</pre>
     if(outcolor & 2) tile_base[1] |= 1<<(7-(7&i));</pre>
// Copy to cart ram.
memcpy(&(SRAM[0][0x0100]),finalbuffer,sizeof(finalbuffer));
```