LED Panel Display Documentation

10x13 RGB dot display matrix that can be daisy chained

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1 Overall device description

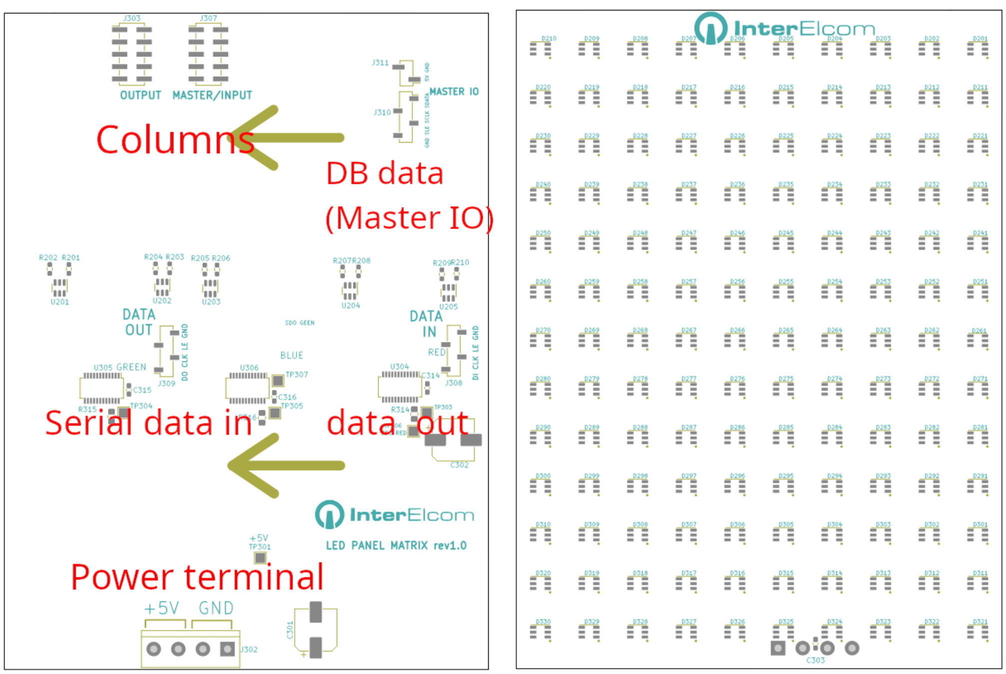
The panel in question is a 10 by 13 RGB pixel array that can be connected in a straight line in order to create an arbitrary length display. Each pixel can be a combination of red, green or blue. No gradient in between is possible. All panels in a line share a common column bus and serial data bus. Panel that is first in line is to be selected as a master by mounting a daughter board on its back. This daughter board serves as controller for whole display and allows for communication via RS-485 interface allowing for management of displayed text.

2 Physical description

2.1 Daisy chaining and panel board interface

Each panel has two connections for the columns that are shared between each board connected in series. In case of a board that is first in line one column line serves as a connection to a master daughter board. In case of each next segment the input and output connector for the column acts as a pass through. The daughter board should connect to the ***Master / Input*** connector and to the ***Master IO*** connector. In addition to ensure the robust mounting of two PCBs a hole for a M2 Screw is provided.

Arrows on the back of the PCB indicate in which way the panels should be arranged.



(a) Back of the PCB

(b) Front of the PCB

Figure 1: Illustration of the board and its connectors

Serial data is daisy chained between the boards meaning that it is not shared in parallel like columns but it passes through a series of shift registers on each connected board. To facilitate this problem each board has a set of four pin connectors marked as Data In and ***Data Out***. The data in should be omitted in case of panel with master daughter board, similarly in case of each panel that follows the master the ***MASTER IO*** should be omitted.
Typical serial connection of panels is shown in fig 2

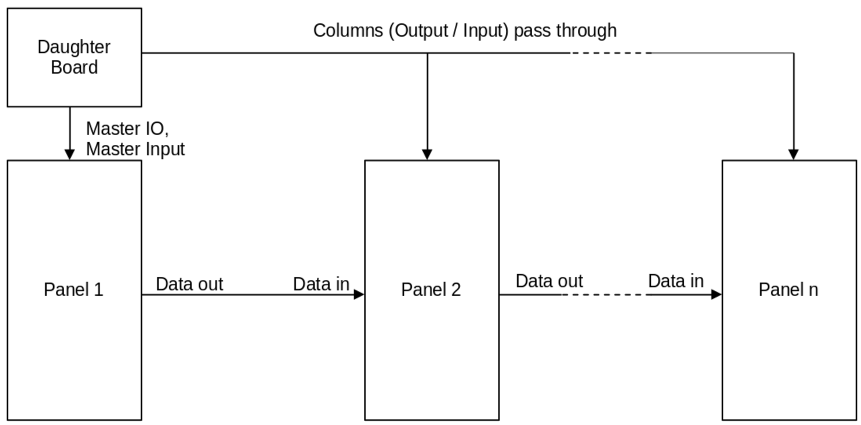
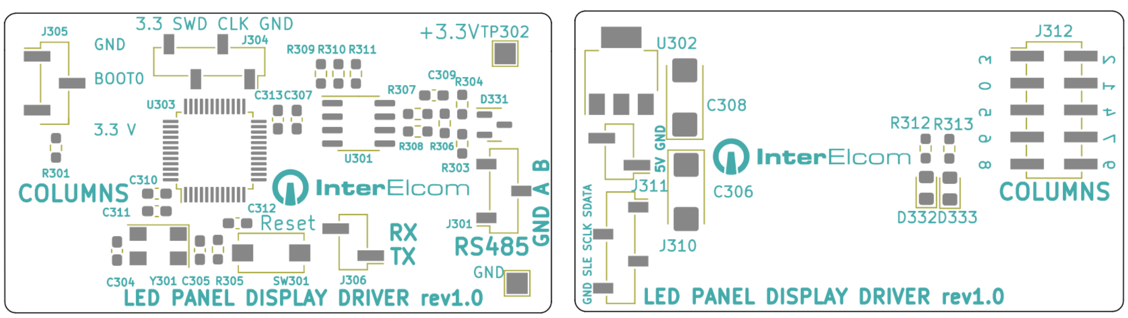


Figure 2: Block diagram of a system consisting of n panels

2.2 Doughter board

Daughter board also referred to as a DB board or a master is a PCB containing a STM32F030 microcontroller and a RS485 half duplex transceiver.
This part sends serial data to the first shift register in series and parallel data to all columns across the whole display. DB connects to a motherboard which should be the first panel in line to ***MASTER/INPUT*** 2 x 5 2.54 mm IDC connector and to ***MASTER IO*** connector which consists of 2 x 1 2.54 mm pin header for 5 V supply rail and 4 x 1 2.54 mm pin header for the serial data connection to the first shift register in line.



(a) Back of the DB

(b) Front of the DB

Figure 3: Illustration of the daughter board

2.3 Power connection and absolute maximum operating conditions

Power to the board is supplied by a 4 pin screw terminal in which there are two positive terminals and two ground terminals this allows for easy daisy chaining by linking one set of terminals from a block to another set of terminals on another block without making special cables for the whole length of the display. Example of such an application is shown in the fig. 4

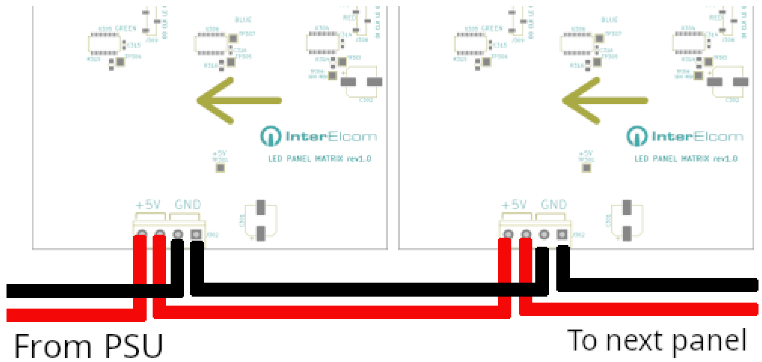


Figure 4: Suggested connection of power to series of panels

2.3.1 Absolute maximum operating conditions

Symbol	Characteristic	Range	unit
+5V VDD	DC power supply	4.5-6	V
DI, CLK, LE	Input voltage	VDD+0.4	V
I_{max}	Maximum current drawn by single panel	8	A
I_{DB}	Maximum current drawn by daughter board master	500	mA
F CLK	Serial clock Frequency	30	MHz
T_{opr}	Ambient temperature of operation	-40+85	C°
T_{stg}	Ambient storage temperature	-55+150	C°

Table 1: Absolute maximum operating conditions

2.4 Design implementation consideration

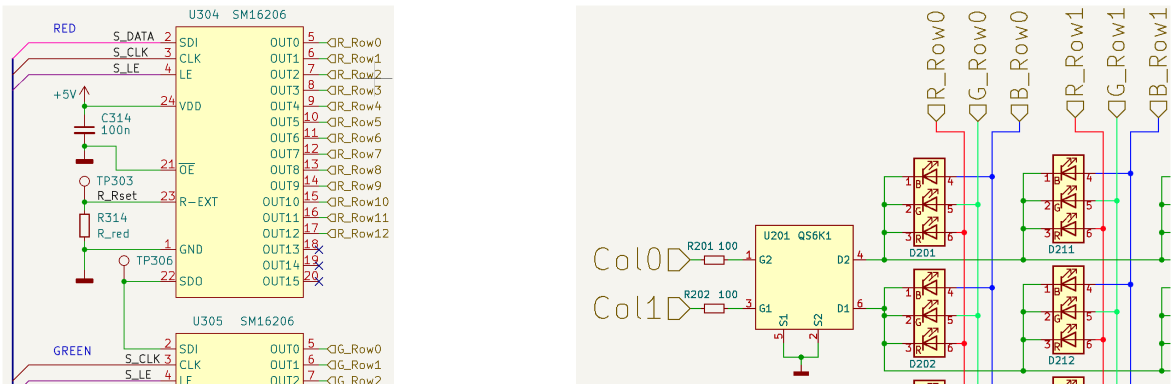
When a longer display is planned to be powered from a single power supply unit attention should be put on the resistance of the cables since in bus configuration presented in fig 4 a significant drop might occur along the power rail. For larger displays a multiple power supplies with common ground can be used to split the current load and to approximate a star topology.

It is also a good practice to connect a power supply with short lead to the panel unit that has the daughter board mounted onto it. This method should prevent significant drops that may occur along the power line from affecting the more sensitive microcontroller.
The maximum current drawn by a panel with daughter board connected to it is equal to $I_{db} + I_{max}$

3 Theory of operation

3.1 Multiplexing and rows

Device bases its operation of the idea of multiplexing. Basically the rows and columns are switched in a certain configuration that allows the current flow to individual diodes without having as many connections on the copper layer as we have diodes.



(a) First shift register of DB

(b) Fundamental part of the matrix

Figure 5: Elements driving the rows and columns

In this case with 10 columns and 13 rows we have 130 diodes but only 23 physical lines to control. This control task is further simplified by the use of SM16206S integrated circuits. This IC consists of a sixteen bit shift register and constant current driver for each channel making it suitable for powering LEDs. Each panel uses three shift registers in series one for each color. Fixed resistors allow change of current that is to be supplied to each color of the panel. Control of the shift registers is done by the microcontroller which sets the latch and provides clock to all the registers in common (these signals are passed through the card and connect to all registers), Microcontroller also feeds the first register in line with serial data which passes through all chain setting the proper output ports to either high or low. This process sets the state of rows.

3.2 Columns and mosfets

There are also 10 pins of the microcontroller that need to set state of columns. As one can see in the figure 5b anodes of the diodes are connected to the rows (ports of SM16206S. Because ports of microcontroller cannot withstand large current flowing through them and since all the current from all panels would sink into these ports mosfets are used on each board to open or close the column to ground. For this task QS61 was chosen. This part consists of two N channel mosfets with low drain to source resistance smaller than 0.364Ω these devices can handle up to 1 A of constant current. Since we use one mosfet per column we can expect current reaching up to 260 mA assuming forward current of 20 mA for each diode. This is safe bulk estimation leaving in safe space of operation with not much of dissipated heat. Since these mosfets are expected to switch rapidly and since all gates are connected to shared bus a series 100 Ω resistors were put between microcontroller and each drain to limit the inrush current to the gate. input capacitance of the chosen mosfet input is approximately 77 pF which is not a large amount for a mcu port but we have consider multiple gates in parallel with long tracks leading to ever larger capacitance and hence choice of series current limiting resistor to each gate is a rational choice.

3.3 LED current setting

Each SM16206S shift register has a constant current driver at each output port allowing for the setting one value of current output for all sixteen channels. Each board has SM16206 IC for red green and blue color. Therefore there are three resistors on each board setting the current for red green and blue LEDs of each pixel. These resistors are marked as R315 for green, R316 for blue and R314 for red color.
Value of resistance that should be presented between R_{ext} port and ground in order yo obtain desired output current I_{out} in mA can be calculated from the formula:

$$R_{ext} = \frac{16500}{I_{out}} \tag{1}$$

Data sheet of the SM16206 also provides a graph of this function as an $f(R_{ext}) = I_{out}$.

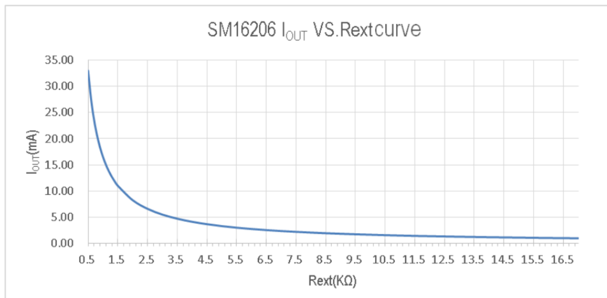


Figure 6: SM16206 output port current curve between IOUT and Rext

This constant current driver will also supply constant current as the voltage input is changing however care should be taken to supply only a V_{DD} that is within the maximum operating conditions specified in table 2.3.1. Higher voltage might cause higher heat dissipation because of the liner regulation in the IC and lack of external current limiting resistors. Lower voltage might trigger brown out detection on the controller daughter board.

Note that each pixel can display not only one of three colors separately but also multiple at once however the limitation is that it cannot mix their intensities limiting its ability to create gradients.

3.4 Doughter board and RS-485 interface

The controller board steps down voltage from 5V (V_{DD}) to 3.3 V for a STM32F030 microcontroller. Daughter board also implements an RS-485 interface so that instruction what to display can be send remotely from another embedded system or computer. For that TI SN65HVD11 is used as a transceiver for half duplex RS 485.

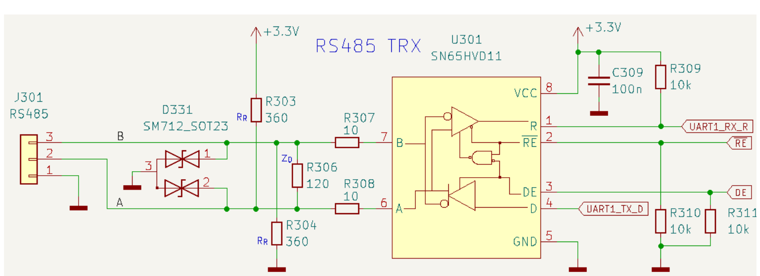
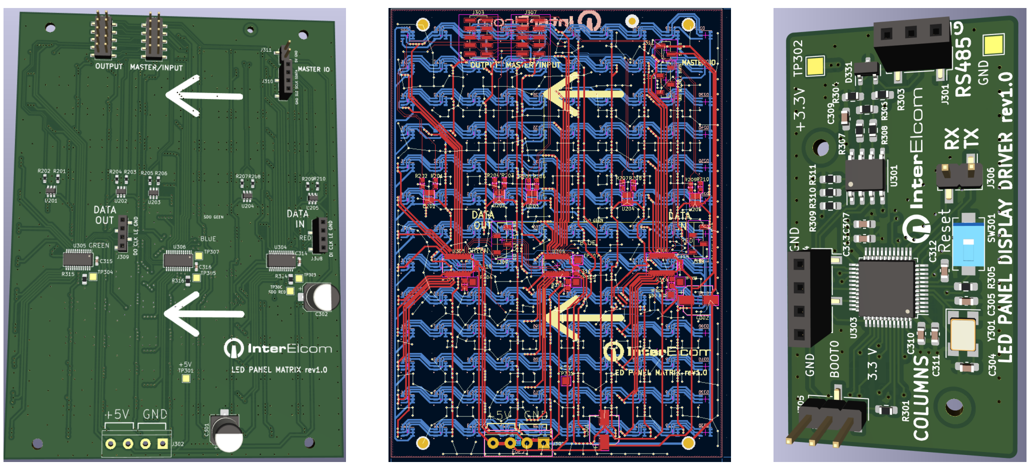


Figure 7: used implementation of RS485 transceiver

ESD protection including TVS diodes and pulse proof resistors was implanted according to a data sheet. Receiver enable and data enable pins are pulled low while receiver pin input is pulled high by 10k resistors each. Similarly to all ICs on this board transceiver supply voltage is decoupled by 100 nF capacitor.

4 PCB layout

Whole project was designed in KiCad 6.0. PCB is a two layer design with dimensions 100 mm by 136 mm. Every component beside the power terminal is surface mounted. Back of the PCB is occupied by the LEDs and each is placed 10 mm apart from another in both horizontal and vertical axis. What is more if two boards are placed next to each other the distance between two LEDs on edge is also 10 mm. PCB also has four holes for the M3 screw for mounting. Each LED is IE-3535 RGB in a 3.5x3.7 mm case with white diffuser at the top. This led is cheap and suitable for an outdoor applications. Absolute maximum forward current is 30 mA for each color, however because of the nonlinear region we will run the LEDs below 20 mA each. All the connectors are mounted o the side of the PCB that is opposite to the LEDs so that clear display can be assembled. Board uses lots of vias in order to provide low resistance to each element of the matrix.



(a) 3D render of the PCB (b) PCB design with no pour (c) Doughter board

Figure 8: Design of panel and daughter board PCBs, DB is not to scale

Layout was designed in such a way that the top copper layer is used for power delivery to the ICs and daughter board as well as serial data between the registers. This top layer is also mostly responsible for column connection since it also has the mosfets on it. Bottom layer mostly the 13 rows and has footprints for all the diodes.

For larger scale manufacturing a via optimization could save some cost. Also a four layer board might turn out to be beneficial since it would save a significant amount of vias necessary.

Daughter board is also a two layer board with dimensions 51.63 mm by 28.254 mm.

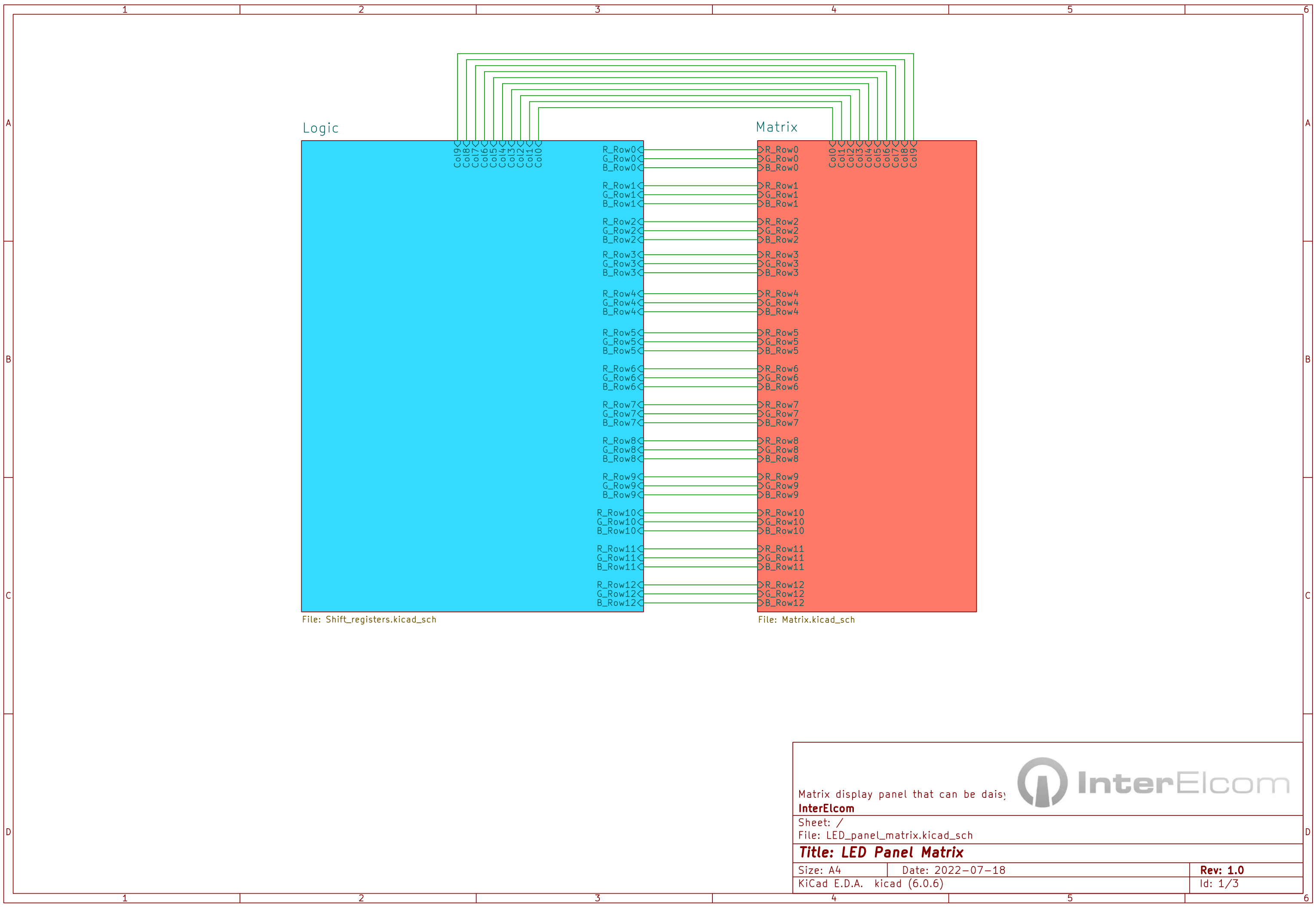
5 BOM

Fully detailed BOM including footprints, side of mounting, manufacturer part number and links is prepared in a separate spreadsheet.

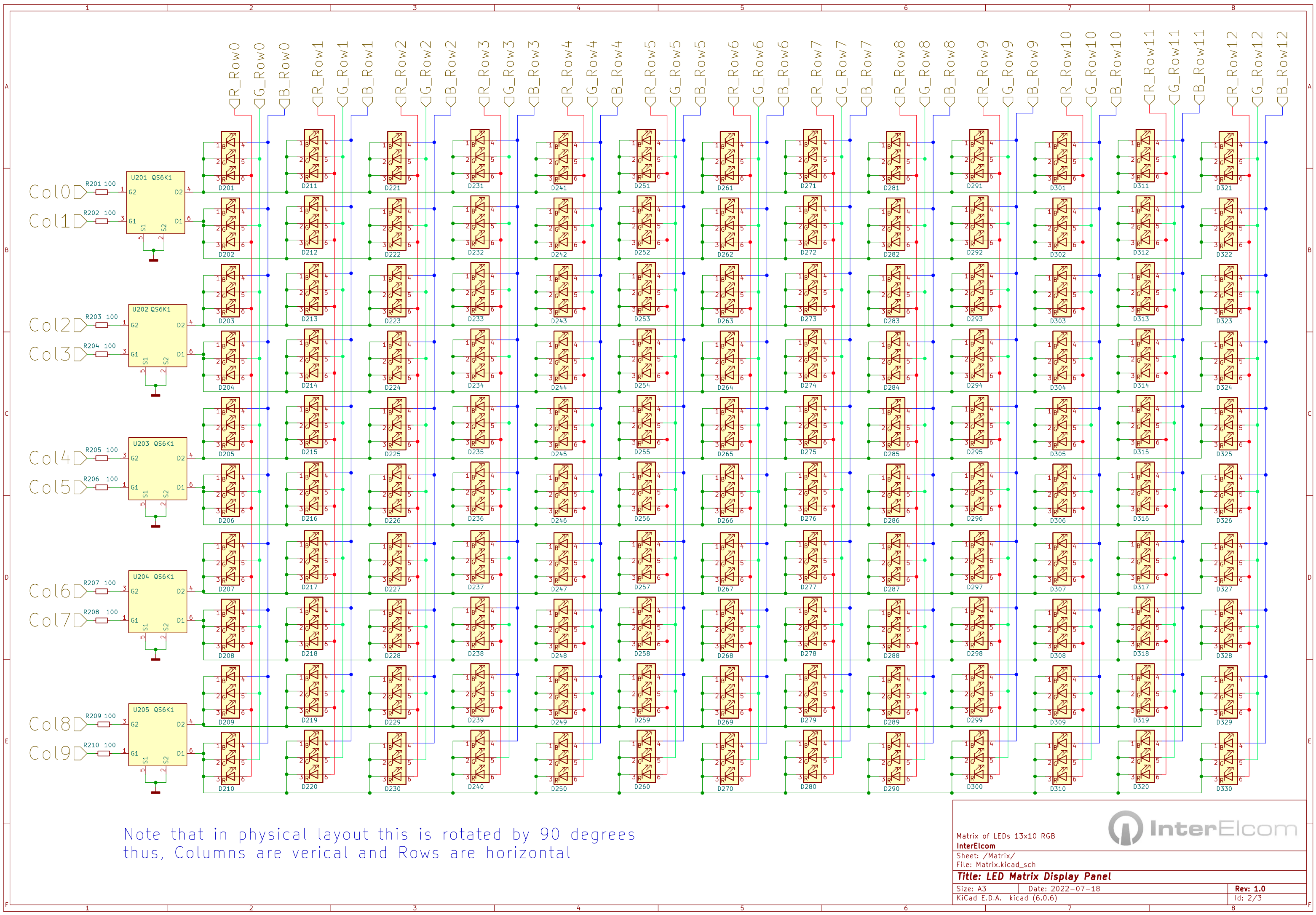
Nr	Comment	Description	Value	Quantity	Designator
1	Electrolytic Capacitor	elect. 220u Cap 16V 8x18mm	220u	2	C301, C302,
2	Capacitor	100nF 50V X7R $\pm$10%	100n	10	C303, C307, C309, C310, C311, C312, C313, C314, C315, C316,
3	Capacitor	20pF 100V NPO $\pm$5%	20p	2	C304, C305,
4	Capacitor Tantalum	10uF 20V	10u	2	C306, C308,
5	RGB LED	SMD 3.5x3.7mm RGB LED	IE-3535	130	D201 to D330
6	TVS diodes, ESD	TVS array SOT23-3 7.5-13.3V	SM712	1	D331,
7	Indicator LED	SMD 0805 LED red	Green	1	D332,
8	Indicator LED	SMD 0805 LED Green	Red	1	D333,
9	RS485 Header	2.54mm pin Header Male	RS485	1	J301,
10	MB Power connector	P5.08 1x4 Screw Terminal	Power Input	1	J302,
11	MB Column connector	IDC 2.54mm SMD pin header	Columns_IO	2	J303, J307,
12	DB ICSP connector	2.54mm pin Header SWD	SWD	1	J304,
13	Boot selector	2.54mm pin Header selection	SELECTOR	1	J305,
14	DB UART connector	2.54mm pin Header 1x3 UART	UART 2	1	J306,
15	MB Serial Data connector	2.54mm pin Header Male 1x4	BUS IO	2	J308, J309
16	Resistor	SMD 0603 10k 0.1W $\pm$5%	10k	6	R301, R302, R305, R309, R310, R311,
17	Resistor	SMD 0603 360 0.2W $\pm$5%	360	2	R303, R304,
18	Resistor, RS 485 Rt	SMD 0603 120 0.1W $\pm$5	120	1	R306,
19	Resistor	SMD 0603 10 1/4W Pulse Proof	10	2	R307, R308,
20	Resistor	SMD 0603 510 0.1W $\pm$5%	510	1	R312,
21	Resistor	SMD 0603 680 0.1W $\pm$5%	680	1	R313,
22	Resistor	SMD 0603 100 0.2W $\pm$5%	100	2	R201, R202, R203, R204, R205, R206, R207, R208, R209, R210
23	Resistor, I set	SMD 0805 820 0.125W $\pm$1%	820	1	R314, R315, R316
24	Tactile Switch	SMD 12VDC SPST	SW_SPST	1	SW301,
25	IC RS485 TRX	RS485 SOIC 8 TRX IC 3.3V	SN65HVD11	1	U301,
26	Voltage regulator	3.3V LDO regulator SOT223	LM1117-3.3	1	U302,
27	MCU	MCU LQFP48 STM32F030C6Tx	STM32F030	1	U303,
28	IC, LED driver	CC 16 bit shift SSOP24	elect	3	U304, U305, U306,
29	Crystal	8MHz $\pm$20ppm 18pF 5.3x3.2mm	8MHz	1	Y301,
30	Mosfet array	2x N channel MOSFET 1A SOT	QS6K1	5	U201, U202, U203, U204, U205
31	DB Column connector	2.54mm pin Header Female 2x5	Columns	1	J312
32	DB Power connector	2.54mm pin Header Female 1x2	+5V GND	1	J311
33	DB Serial Data connector	2.54mm pin Header Female 1x4	Bus IO	1	J305

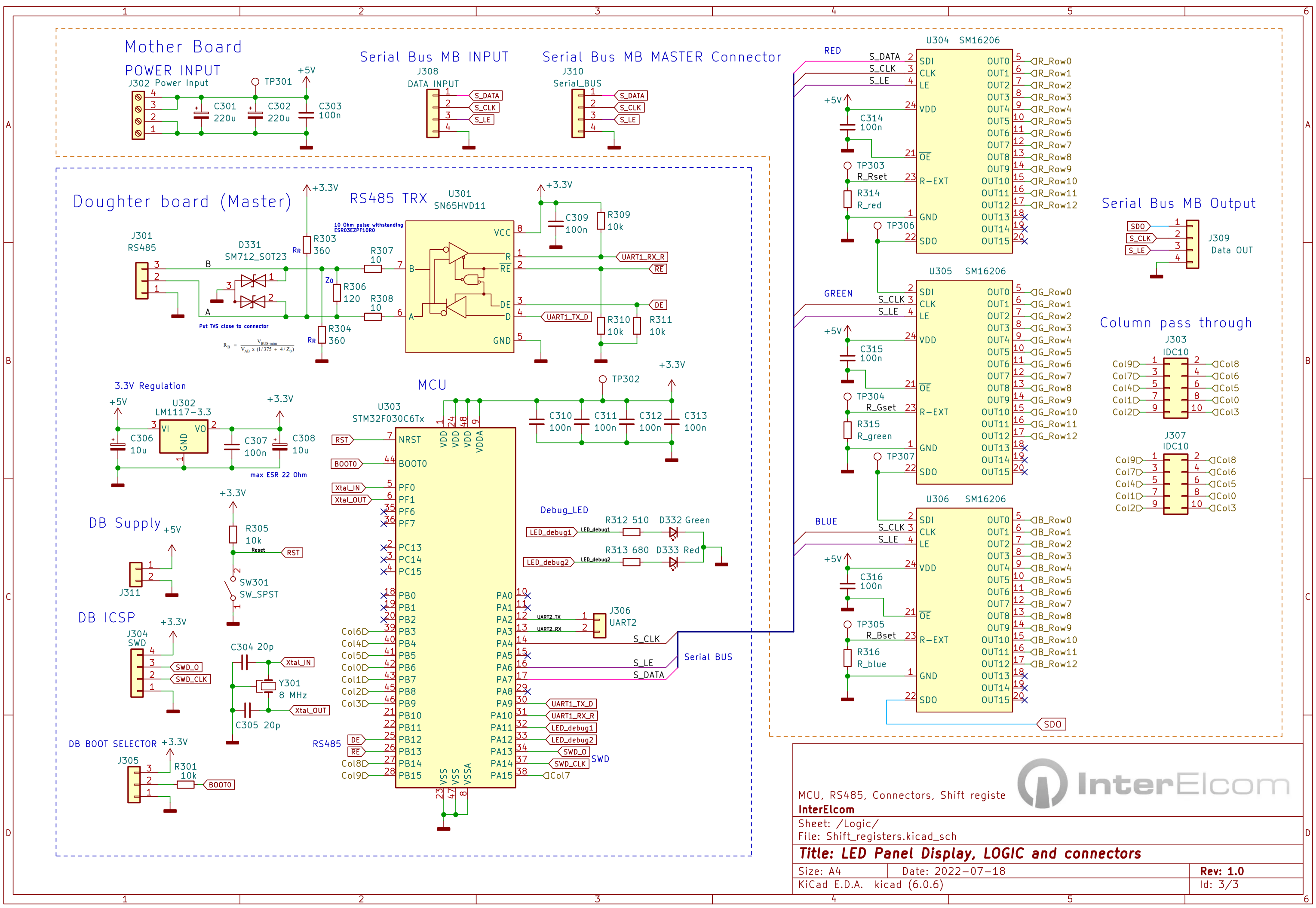
Table 2: Bill of materials

6 Schematic



Logic
Col9 Col8 Col7 Col6 Col5 Col4 Col3 Col2 Col1 Col0
R_Row0 G_Row0 B_Row0
R_Row1 G_Row1 B_Row1
R_Row2 G_Row2 B_Row2
R_Row3 G_Row3 B_Row3
R_Row4 G_Row4 B_Row4
R_Row5 G_Row5 B_Row5
R_Row6 G_Row6 B_Row6
R_Row7 G_Row7 B_Row7
R_Row8 G_Row8 B_Row8
R_Row9 G_Row9 B_Row9
R_Row10 G_Row10 B_Row10
R_Row11 G_Row11 B_Row11
R_Row12 G_Row12 B_Row12
File: Shift_registers.kicad_sch
Matrix
Col0 Col1 Col2 Col3 Col4 Col5 Col6 Col7 Col8 Col9
R_Row0 G_Row0 B_Row0
R_Row1 G_Row1 B_Row1
R_Row2 G_Row2 B_Row2
R_Row3 G_Row3 B_Row3
R_Row4 G_Row4 B_Row4
R_Row5 G_Row5 B_Row5
R_Row6 G_Row6 B_Row6
R_Row7 G_Row7 B_Row7
R_Row8 G_Row8 B_Row8
R_Row9 G_Row9 B_Row9
R_Row10 G_Row10 B_Row10
R_Row11 G_Row11 B_Row11
R_Row12 G_Row12 B_Row12
File: Matrix.kicad_sch
Matrix display panel that can be dais
InterElcom
InterElcom
Sheet: /
File: LED_panel_matrix.kicad_sch
Title: LED Panel Matrix
Size: A4
Date: 2022-07-18
Rev: 1.0
KiCad E.D.A. kicad (6.0.6)
Id: 1/3


R_Row0 G_Row0 B_Row0 R_Row1 G_Row1 B_Row1 R_Row2 G_Row2 B_Row2 R_Row3 G_Row3 B_Row3 R_Row4 G_Row4 B_Row4 R_Row5 G_Row5 B_Row5 R_Row6 G_Row6 B_Row6 R_Row7 G_Row7 B_Row7 R_Row8 G_Row8 B_Row8 R_Row9 G_Row9 B_Row9 R_Row10 G_Row10 B_Row10 R_Row11 G_Row11 B_Row11 R_Row12 G_Row12 B_Row12
Col0
Col1
Col2
Col3
Col4
Col5
Col6
Col7
Col8
Col9
U201 QS6K1
U202 QS6K1
U203 QS6K1
U204 QS6K1
U205 QS6K1
Note that in physical layout this is rotated by 90 degrees
thus, Columns are verical and Rows are horizontal
InterElcom
Matrix of LEDs 13x10 RGB
InterElcom
Sheet: /Matrix/
File: Matrix.kicad_sch
Title: LED Matrix Display Panel
Size: A3 Date: 2022-07-18 Rev: 1.0
KiCad E.D.A. kicad (6.0.6) Id: 2/3


Mother Board
POWER INPUT
J302 Power Input
TP301
+5V
C301 220u
C302 220u
C303 100n
Serial Bus MB INPUT
J308
DATA INPUT
S_DATA
S_CLK
S_LE
Serial Bus MB MASTER Connector
J310
Serial_BUS
RED
GREEN
BLUE
U304 SM16206
U305 SM16206
U306 SM16206
SDI
CLK
LE
VDD
OE
R-EXT
GND
SDO
C314 100n
TP303
R314 R_red
TP306
C315 100n
TP304
R315 R_green
TP307
C316 100n
TP305
R316 R_blue
SDO
Serial Bus MB Output
J309 Data OUT
Column pass through
J303 IDC10
J307 IDC10
Doughter board (Master)
RS485 TRX
U301 SN65HVD11
J301 RS485
D331 SM712_SOT23
R303 360
R304 360
R306 120
R307 10
R308 10
R309 10k
R310 10k
R311 10k
C309 100n
10 Ohm pulse withstanding ESR03EZPF10R0
Put TVS close to connector
UART1_RX_R
UART1_TX_D
RE
DE
+3.3V
3.3V Regulation
U302 LM1117-3.3
C306 10u
C307 100n
C308 10u
max ESR 22 Ohm
MCU
U303 STM32F030C6Tx
TP302
C310 100n
C311 100n
C312 100n
C313 100n
NRST
BOOT0
RST
Xtal_IN
Xtal_OUT
Debug_LED
R312 510
D332 Green
R313 680
D333 Red
LED_debug1
LED_debug2
J306 UART2
Serial BUS
S_CLK
S_LE
S_DATA
SWD
SWD_O
SWD_CLK
RS485
DB Supply
J311
R305 10k
Reset
SW301 SW_SPST
DB ICSP
J304 SWD
C304 20p
C305 20p
Y301 8 MHz
DB BOOT SELECTOR
J305
R301 10k
MCU, RS485, Connectors, Shift registe
InterElcom
Sheet: /Logic/
File: Shift_registers.kicad_sch
Title: LED Panel Display, LOGIC and connectors
Size: A4
Date: 2022-07-18
KiCad E.D.A. kicad (6.0.6)
Rev: 1.0
Id: 3/3

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