Accessing individual 75-micron diameter nozzles of a desktop inkjet printer to dispense picoliter droplets on demand

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ESC-P2 Client Manual

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Introduction

This manual describes the usage of the software that can be used to control individual nozzles on an Epson desktop drop on demand inkjet printer. The methods used were tested, and found to be working as described, for six different Epson printers, being the Epson Stylus SX235W, Epson Stylus SX600FW, Epson Stylus Photo RX520, Epson Stylus DX6050, Epson Expression Home XP-235 and the Epson Expression Home XP-245.

It is presumed that the software will also work on new Epson printers, since up till now the Epson printers are backwards compatible with the older programming language.

Contents

1 Installation of necessary software

To obtain full software control over an Epson printer in Linux, some software has to be installed. The steps to install this software are described in this section and result in obtaining binary files from a printer driver (Gutenprint) that an Epson printer directly can read and print.

1.1 Install Linux

All experiments were conducted by controlling the printer from Linux. Using Linux makes obtaining raw printer files easier in contrast to the Windows operating system. In Linux for more than 600 types of Epson printers open source printer drivers are available. These particular drivers (Gutenprint) will output the binary files in the ESC/P2 language, which is not possible in Windows.

All necessary functions to control the printer can be accessed from a virtual machine. On a Windows PC, Linux can be easily operated in VirtualBox. VirtualBox is open source software wherein a Linux guest can be intalled on a Windows host (and vice versa). Oracle VirtualBox 5.1 was used to create an Ubuntu 16.04 guest on a Windows 10 host.

1.2 Install Gutenprint

To obtain the print spooler output in a readable format, Gutenprint drivers are used instead of the standard Linux drivers Epson provides. The Epson Linux drivers create binary data in the ESC-P Raster language, for which Epson did not publish a manual. Gutenprint drivers create binary files with ESC/P2 commands, for which Epson published a Programming Guide[1].

First download Gutenprint 5.2.11 at `https://sourceforge.net/projects/gimp-print/files/` in the `tar.bz2` format, which is the default option for Linux. Next extract the file and move the folder to the `Home (~/)` directory (for easy acces) by opening a terminal in the `Downloads` directory and execute in the terminal window:

```
tar xvjf gutenprint-5.2.11.tar.bz2
mv gutenprint-5.2.11/ ~/gutenprint
cd ~/gutenprint
./configure
make
sudo make install
```

to install Gutenprint to the system. More details about the installation and build of the package can be found on the Gutenprint project page `http://gimp-print.sourceforge.net/index.php`.

1.3 Install ESC/P2 Client

The ESC commands in the ESC/P2 machine language can be generated using the newly developed ESC/P2 Client. This client can be installed by the following steps. The program uses `python3`, which is default installed on Ubuntu, and (the unprint function) uses the Gutenprint 5.2.11 installation files. These files need to be present in the `~/gutenprint` folder (as described in the previous section). For automatic installation on a Linux system, extract the zip file, open a terminal in the extracted folder, and run the following commands to install the software:

```
sudo chmod +x install
./install
```

The software is installed to the home directory and the necessary Python modules are automatically installed. The program can be run from the created shortcut on the desktop.

For manual installation the `zip` file can be extracted to any directory. The program uses the following `python3` modules:

```
prettytable
tkinter
```

To be able to use all functions of the program the `unprint` C++ script has to be made executable:

```
sudo chmod +x ESCP2-Client/gutenprint/unprint
```

The program can be run by opening a terminal and executing:

```
python3 main_gui.py
```

The client can be used on Windows as well, only to generate the ESC command sequences, and save these to a `prn` file.

2 Usage of different software

2.1 Gutenprint

Although Gutenprint mainly used to obtain the output of the print spooler in an understandable format, it also comes with some viewing and data-gathering tools. These can be found in the `test` folder in the Gutenprint directory. The relevant tools are described below.

Image reconstitution: `unprint`

Unprint is a C script to reconstitute an image from an Epson inkjet output file. It creates a PPM file[2], which displays all dots to be printed as pixels and can be viewed using e.g. `GIMP`. The script should already be compiled, if not execute:

```
gcc unprint.c -o unprint
```

to compile it to the executable file `unprint`. To reconstitute a `prn` file execute the program issuing:

```
unprint input.prn output.pnm
```

Data-gathering: `parse-escp2`

The output of the file printer is a binary file containing ESC-P2 commands, which can be viewed in any binary editor. However it is very hard to read all the commands in this binary editor since the commands are all displayed in single file. To view the file in a more readible format a `Perl` script called `parse-escp2` can be used. To view the output of the script open a terminal in the `test` folder and execute:

```
perl parse-escp2 input.prn
```

The parse script also has some options to display the binary file with more details, e.g. nozzle image data and positioning data, and the output of the script can be saved to a text file. The use of these options and their description are shown in table 1.

Table 1: Synopsis and options for the `parse-escp2` `Perl` script, which can be used to view the hexadecimal bytes in a `prn` file with `ESC` commands.

Synopsis	`perl parse-escp2 [option] input.prn`	
Options	`-v`	Shows a brief explanation for each ESC command along with some values, e.g. the horizontal and vertical position and units.
	`-V`	Decompresses and shows the run length encoded image data for each nozzle in hexadecimal bytes.
Save output	`perl parse-escp2 input.prn > textfile.txt`	
		Saves the output of the parse script to a plain textfile.

2.2 CUPS

To print a normal file in CUPS to the default printer,

```
lp <file>
```

To print to a specific printer with name <printername>

```
lp -d <printername> <file>
```

To print a binary file to a specific printer, it is required to indicate that the file does not need to be rasterized again, which is done by,

```
lp -d <printername> -oraw <file>.prn
```

When CUPS is not responding to the print commands, there are a couple of commands that can help with solving the problem. Some of these can be found in table 2, more information can be found on the CUPS documentation page https://www.cups.org/documentation.html.

Table 2: Frequently used command to debug problems with printer connection and the CUPS print service

Command	Description
lpstat	Print information about the status of the LP print service
lpstat -v	Shows all installed printers on the system, including the path names of the printer output devices
lsusb	Shows all connected USB devices
cancel -a	Cancels all active print jobs
sudo /etc/init.d/cups restart	Restarts the CUPS printer service

2.3 Ubuntu Aliases

To make the execution of some long commands more easy aliases can be used in Ubuntu. To add aliases simply open a terminal and execute:

```
gedit ~/.bash_aliases
```

In this file new commands can be added as follows:

```
alias <NewCommandName>="command -options"
```

For example, an alias to print a raw prn file to the printer with name Epson-Stylus-SX235W:

```
alias lpsx235w="lp -d Epson-Stylus-SX235W -oraw"
```

3 Obtain binary print files

3.1 Add file printer to CUPS

To obtain the binary output of the print spooler a file printer has to be added to the system. Macintosch OS X and most Linux distributions use CUPS (Common Unix Printing System) as print spooler, so CUPS is installed along with the operating system. To add a file printer to CUPS first some changes need to be made to the CUPS configuration file. To do this open this file in a text editor (e.g. gedit) from the terminal by executing:

```
gedit /etc/cups/cups-files.conf
```

Add the following line to the file (case sensitive):

```
FileDevice Yes
```

Next restart CUPS by executing:

```
sudo /etc/init.d/cups restart
```

Now CUPS is setup to add file printers with a specified driver, in this case a Gutenprint driver. To add a file printer open a web browser and follow these steps:

1. Open http://localhost:631/ in a web browser. If there cannot be made a connection, CUPS needs to be restarted by executing:

   ```
   sudo /etc/init.d/cups restart
   ```

   Give the password of the device in use and refresh http://localhost:631/ in the browser.

2. Click under 'CUPS for Administrators': 'Adding Printers and Classes'.

3. Click under 'Printers': 'Add Printer' and login with root privileges.

4. Click 'LPD/LPR Host or Printer' and continue. Type file:/tmp/<outputfilename>.prn and continue, with <outputfilename> an arbitrary name. This directory is chosen since CUPS doesn't have access to the home directory, so it has to be linked to a temporary directory (tmp).

5. Name the printer (e.g. fileprinter1). Scroll to Epson in the 'Make' menu and continue.

6. When scrolling down to the right Epson printer in the 'Model' menu (make sure to use the right model with CUPS+Gutenprint v5.2.11 (en) in the name) and add the printer.

7. The last step is to accept the default options. The printer has been added.

3.2 Generating simple printer output

When the printer is added, the raw files can be obtained. Printing with the created printer is possible now with the command lp. To print an arbitrary (preferably small) file to the newly created file printer and obtain the binary output type:

```
lp -d <fileprintername> <filename>
```

When executing this, the command lp rasterizes the file using the printer drivers and saves the output to the temporary directory as a .prn file. The next step is to copy the .prn file to a specific folder in the home directory. This is necessary, because it is not possible to work and adjust files in the temporary directory.

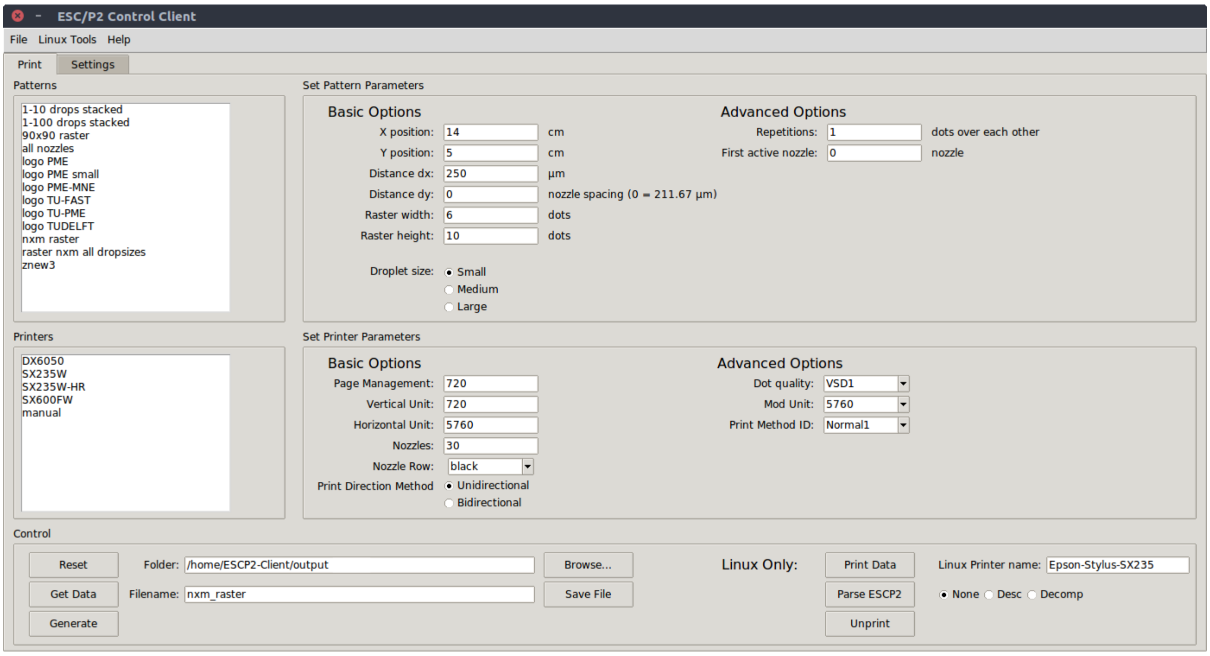
Now execute in the terminal window the single line command:

```
sudo cp /tmp/<outputfilename>.prn . &&
     sudo chmod 777 <outputfilename>.prn &&
     mv <outputfilename>.prn <newname>.prn
```

Make sure that <outputfilename>.prn is the same as the filename created in section 3.1 point 4 and that the command above is executing in the specific folder in the home directory.

The <newname>.prn is a raw printing file that now can be shown in a readable format using the commands described in section 2.1

4 Using the GUI



Patterns

1-10 drops stacked
1-100 drops stacked
90x90 raster
all nozzles
logo PME
logo PME small
logo PME-MNE
logo TU-FAST
logo TU-PME
logo TUDELFT
nxm raster
raster nxm all dropsizes
znew3

Set Pattern Parameters

Basic Options

X position: 14 cm
Y position: 5 cm
Distance dx: 250 µm
Distance dy: 0 nozzle spacing (0 = 211.67 µm)
Raster width: 6 dots
Raster height: 10 dots

Droplet size: ● Small ○ Medium ○ Large

Advanced Options

Repetitions: 1 dots over each other
First active nozzle: 0 nozzle

Printers

DX6050
SX235W
SX235W-HR
SX600FW
manual

Set Printer Parameters

Basic Options

Page Management: 720
Vertical Unit: 720
Horizontal Unit: 5760
Nozzles: 30
Nozzle Row: black
Print Direction Method ● Unidirectional ○ Bidirectional

Advanced Options

Dot quality: VSD1
Mod Unit: 5760
Print Method ID: Normal1

Control

Folder: /home/ESCP2-Client/output
Filename: nxm_raster

Linux Printer name: Epson-Stylus-SX235
● None ○ Desc ○ Decomp

4.1 Print a pattern

To print a pattern, follow the following steps:

1. Select a pattern on the top left
2. Set the options for the pattern (detailed explanation below)
3. Select a printer on the bottom left
4. Set the printer parameters
5. Choose what to do with the selected pattern:
   - Save the file to a folder for later use
     (a) Click on the bottom left on 'Generate' to generate the selected pattern
     (b) Click 'Browse...' to select a folder, or type in the path manually
     (c) Set a file name in the 'Filename' input box
     (d) Click 'Save File' to store the file in the specified directory
   - Directly print the file from the GUI (Linux only)
     (a) Specify the exact printer name as setup in the printer settings
     (b) Click on 'Print Data' to send the raw print file directly to the printer

4.2 Pattern parameters

For the various available patterns, some parameters can be changed. The parameters that can be changed depend on the selected pattern. The parameters are listed in table 3

Table 3: Add caption

Parameter	Description
X position	Set the x position of the pattern in cm's, the default (14 cm) prints on a fixed substrate located on the left in the printer
Y position	Set the y position on a flexible substrate, is not meaningful when printing on a fixed substrate
Distance dx	Sets the horizontal distance between the droplets in um's
Distance dy	Sets the vertical distance between the droplets, expressed in number of nozzles to leave out. This is based on the printhead geometry, and will result in a multiple of 211.67 um. The real vertical spacing = (entered value + 1)*211.67 um
Raster width	Sets the raster width in number of droplets
Raster height	Sets the raster height in number of droplets
Droplet size	Sets the droplet size
Repetitions	Sets the number of repetitions of the pattern, making it possible to print multiple patterns on top of each other, to make sure there is enough fluid on the designated spot
First active nozzle	Sets the first active nozzle on the printhead, shifting the entire pattern down over the available nozzles. If the pattern is 25 droplets in height, the first active nozzle must be between the 0th and the 4th (nozzle numbering starts at 0)
Width scaling	When printing a matrix, the distance between the droplets can be tuned using this parameter. When set to 3, the horizontal and vertical distance is approximately equal. When set to 0, the droplets almost overlap.

5 Generate custom binary ESC print files

The developed Python script can be used to create a custom prn file. The script can be used to control the drop size, the number of droplets to dispense, the location to dispense and has some images presets that can be printed. To compose a printer file that the printer can handle, a specific format needs to be used. In the following sections the most important functions will be explained.

5.1 File structure

Every Epson print file is compiled in the same way. Each ESC/P2 code has a header, body, image data and a footer. In table 4 is the sequence of commands shown. The header and the footer is for every file the same. The image data is loop that is executed for every print file. This loop is clarified with figure 1 on the following page. When a new page is loaded, first the raster is defined. In this raster, information about the position where to print is determined. When the printhead and the paper reach this position, dispensing of droplets is started. Immediately when the paper moves further, a new raster is defined. This cycle continues till the page is full. If a new page has to be printed, first the form feed is added and the cycle starts over. Else, after the form feed the footer is added and the file is complete.

Table 4: Command sequence for printing[1]

Transfer cycle	Details of setting	Items set	Commands used
By document	Initialise settings (Header)	Initialise printer	ESC @
		Enter remote mode	ESC (R
		Paper Feed Setup	SN
		Set Media information	MI
		Exit Remote Mode	ESC 00H 00H 00H
	Printing method control (Body)	Selects graphics mode	ESC (G
		Set unit	ESC (U
		Select Monochrome or Color	ESC (K
		Select MicroWeave printing mode	ESC (i
		Turn unidirectional mode on/off	ESC U
		Selects Ink Drop Size	ESC (e
		Set resolution of Raster mode	ESC (D
	Set print format (Body)	Set page format	ESC (c or ESC (C
		Set paper dimension	ESC (S
		Set print method ID	ESC (m
Loop (see 5.1) By raster	Set vertical position Set transfer data (Image data)	Set vertical print position	ESC (V or ESC (v
		Set horizontal position	ESC ($
		Print raster graphics:	ESC i
		repeat above for each color	
By page	Form feed	Form feed	FF
	Terminate printing (Footer)	Initialise printer	ESC @
		Enter Remote mode	ESC (R
		Load NVR settings	LD
		Job end	JE
		Exit Remote mode	ESC 00H 00H 00H

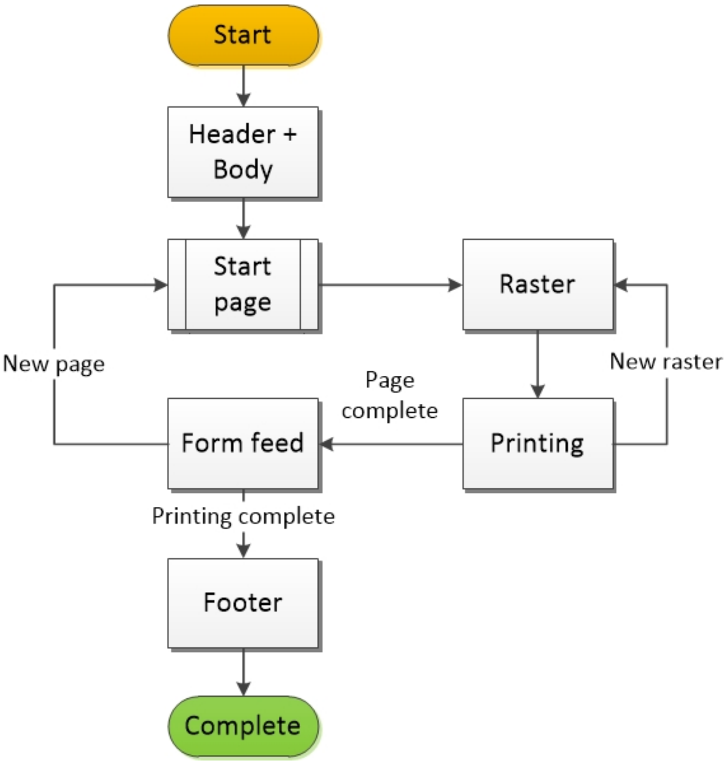


Figure 1: When a new page is loaded, first the raster is defined. In this raster, information about the position where to print is determined. When the printhead and the paper reach this position, dispensing of droplets is started. Immediately when the paper moves further, a new raster is defined. This cycle continues till the page is full. If a new page have to be printed, first the form feed is added and the cycle starts over. Else, after the form feed the footer is added and the file is complete.

5.2 Send generated file to the printer

Once a file is generated using the functions described hereafter, it can be send to the printer by issuing the commands described in section 2.2.

To check the integrity of the file, it can be useful to first parse it with the Gutenprint `parse-escp2` script:

```
perl parse-escp2 <file>.prn
```

If there are some errors in the file (e.g. line feed missing, number of bytes mismatch, etc.) the output can be mangled. If trying to print such a corrupt file, the printer will start to output some garbage. However, not all mistakes can be found by this script, so a second check can be the use of the `unprint` function:

```
unprint <file>.prn <output>.pnm
```

The output file can be viewed using a PPM or PNM viewer.

5.3 Binary file handling functions

The binary print files can be separated into three sections, header, body and footer. The header and footer section are specific for each printer model and can be used later to create custom print files. To split the printer output in these three sections a python script can be used.

Syntax	`split_prn(printername, filepath, outputfolder='prns')`	
Parameters	Name	Type
	`printername`	string
	`filepath`	string
	`outputfolder`	string (optional))
Description	Load a prn file and splits it into a header, body and footer file. Specify `printername`, original prn `filepath` and the desired `outputfolder`. Splits the prn file is three sections, header, body and footer, which can be loaded later on to create a custom prn file. File is saved as: `<outputfolder>/<printername>-[section].prn`	

Syntax	`save_prn_file(input, filename, folder='')`	
Parameters	Name	Type
	`input`	byte string
	`filename`	string
	`folder`	string (optional)
Description	Saves the contents of a byte string to a binary print file, the `filename` can be a complete path, or the path can be specified separately in the `folder` argument.	
Example	`>>> save_prn_file(header, 'prns/sx235w/sx235w-header.prn')` Saves the contents of the specified variable to a binary file	

Syntax	`data_splitter(data)`	
Parameters	Name	Type
	`data`	hexadecimal bytes
Description	Splits hexadecimal data with delimiter `b'\x1b'`. Returns the split data in a list containing the hexadecimal bytes. If the data does not start with an ESC, the data till the first occurrence of an ESC is saved at the first position in the list	

Syntax	`load_prn_file(filename)`	
Parameters	Name	Type
	`filename`	string
Description	Load the contents of a binary print file to a variable.	
Example	`>>> header = load_prn_file('prns/sx235w/sx235w-header.prn')` Loads the contents of the specified file to the header variable	

5.4 ESC Body functions in python

Table 5: ESC (G: Select graphics mode

Syntax	`ESC_Graph()`
Parameters	–
Description	See section 6.2 for more information. Generates necessary data for ESC command to turn on graphics mode

Table 6: ESC (U: Set units

Syntax	`ESC_Units(pmgmt = 720,vert = 720,hor = 5760,m = 5760)`	
Parameters	Name	Type
	`pmgmt`	integer
	`vert`	integer
	`hor`	integer
	`m`	integer
Description	See section 6.3 for more information. Sets the page units according to the given arguments and generates the required hexadecimal data. The accepted units depend on the printer model. Default values (Epson SX235W): `pmgmt = 720` sets page management units to `1/720` inch `pmgmt = 720` sets page management units to `1/720` inch `hor = 5760` sets horizontal units to `1/5760` inch `m = 5760` sets base units to 5760 `m` is needed to calculate the P, V and H values in the ESC command as a multiple of `m`, to reduce the number bytes.	

Table 7: ESC (K: Monochrome / Color mode

Syntax	`ESC_Kmode(n=b'\x02')`	
Parameters	Name	Type
	`n`	hexadecimal byte
Description	See section 6.4 for more information. Creates hexadecimal bytes to set the printer in color or monochrome mode, depending of the value of `n`. Default value: `n=b'\x02'`, sets the printer in color mode (printer default)	

Table 8: ESC (i: Set Microweave mode

Syntax	`ESC_imode(n=b'\x01')`	
Parameters	Name	Type
	`n`	hexadecimal byte
Description	See section 6.15 for more information. Deselects MicroWeave mode, an old print method used for printers with small buffer sizes. Without this command MicroWeave mode is on, with `n` set to `b'\x21'` MicroWeave mode is off.	

Table 9: ESC U: Unidirectional mode on/off

Syntax	`ESC_Umode(n=b'\x01')`	
Parameters	Name	Type
	`n`	hexadecimal byte
Description	See section 6.6 for more information. Sets the printer in uni- or bi-directional mode, depending of the value of `n`. Default value: `n=b'\x01'`, sets the printer unidirectional mode, which results in a higher accuracy.	

Table 10: ESC (e: Select dot size

Syntax	`ESC_edot(d=b'\x12')`	
Parameters	Name	Type
	`n`	hexadecimal byte
Description	See section 6.7 for more information. Sets the available dot sizes, depending of the value of `d`. Default value: `n=b'\x12'`, sets the data per dot to 2 bits , which results three possible dot sizes (small, medium and large). See section 6.17 for possible print qualities.	

Table 11: ESC (D: Set image raster resolution

Syntax	`ESC_Dras(v=120,h=40)`	
Parameters	Name	Type
	`v`	integer
	`h`	integer
Description	See section 6.8 for more information. Sets the image raster resoltion, depending of the value of `v` and `h` (resp. vertical and horizontal). Possible resoltions can be fount in section 6.17.	

Table 12: ESC (C: Set page length

Syntax	`ESC_C(pmgmt,m)`	
Parameters	Name	Type
	`pmgmt`	integer
	`m`	integer
Description	See section 6.9 for more information. Sets the length of the page in inches, `m` is the length of the page in inches and using `pmgmt` (page management units) the functions expresses the length of the page in the specified units.	

Table 13: ESC (c: Set page format

Syntax	`ESC_c(pmgmt,t,b)`	
Parameters	Name	Type
	`pmgmt`	integer
	`t`	integer
	`b`	integer
Description	See section 6.10 for more information. Sets the page margins of the page in inches, `t` sets the top margin and `b` sets the bottom marging using `pmgmt` (page management units). The coordinate system is set at the top margin of the page (section 6.16).	

Table 14: ESC (S: Set paper dimensions

Syntax	`ESC_c(pmgmt,w,l)`	
Parameters	Name	Type
	`pmgmt`	integer
	`w`	integer
	`l`	integer
Description	See section 6.11 for more information. Sets the paper dimensions in inches, `w` sets the width and `l` sets the length of the page in the defined `pmgmt` (page management units).	

Table 15: ESC (m: Set print method ID

Syntax	`ESC_m(m=b'\x21')`	
Parameters	Name	Type
	`m`	hexadecimal byte
Description	See section 6.12 for more information. Sets the print method according to the value of `n`, possible values are listed in section 6.18. Default printing method is set to plain paper draft: `b'\x21'`.	

5.5 ESC Image data functions in python

Table 16: ESC (V: Set absolute vertical print position

Syntax	`ESC_V(vert,y)`	
Parameters	Name	Type
	`vert`	integer
	`y`	integer
Description	Sets the current vertical print position, the vertical page units (`vert`) must be provided to set the absolute vertical position to `y` inches.	

Table 17: ESC (v: Set relative vertical print position

Syntax	`ESC_v(vert,y)`	
Parameters	Name	Type
	`vert`	integer
	`y`	integer
Description	See section 6.13 for more information. Sets the current vertical print position relative to the previous vertical print position. The vertical page units (`vert`) must be provided to set the relative vertical position to `y` inches.	

Table 18: ESC ($: Set absolute horizontal print position

Syntax	`ESC_dollar(hor,x)`	
Parameters	Name	Type
	`hor`	integer
	`x`	integer
Description	See section 6.14 for more information. Sets the current horizontal print position, the horizontal page units (`hor`) must be provided to set the absolute horizontal print position to `x` inches.	

Table 19: ESC i: Transfer raster image data

Syntax	`ESC_i(r=b'\60',n=722,m=30,an=1,dots=1,size=1)`	
Parameters	Name	Type
	`r`	hexadecimal byte
	`n`	integer
	`m`	integer
	`an`	integer
	`dots`	integer
	`size`	integer
Description	See section 6.5 for more information. Creates the raster image data to print a horizontal line of dots using the selected active nozzle. Parameter description: `r` Select color `n` set number of horizontal bytes `m` set number of nozzles `an` set active nozzle `dots` select number of dots `size` Select size (`1=small, 2=medium, 3=large`) The number of horizontal bytes can be changed, one byte represents 4 dots (default setting: 1 dot is 2 bits), the spacing between the horizontal dots is determined by the horizontal page units. The number of nozzles sets the vertical raster size. The resulting raster data equals `n` $*$ `m` bytes. For printers with 128 nozzles and documents with default page margins this results in $128 * 722 = 92416$ bytes. This data is compressed using run length encoding. This command is closed with `CR` (carriage return), resetting the horizontal print position to `0`. After the last image data the page is printed with `FF` (form feed).	

<table>
<tr><td>Syntax</td><td colspan="2"><code>ESC_i_nrs(nozzlelist,r=b'\x00', size=1)</code></td></tr>
<tr><td rowspan="4">Parameters</td><td>Name</td><td>Type</td></tr>
<tr><td><code>nozzlelist</code></td><td>list</td></tr>
<tr><td><code>r</code></td><td>hexadecimal byte</td></tr>
<tr><td><code>size</code></td><td>integer</td></tr>
<tr><td>Description</td><td colspan="2">See section 6.5 for more information.
Creates the raster image data to print one vertical row of dots using the selected nozzles at a specified location
Parameter description:
<code>nozzlelist</code> a list with active nozzles
<code>r</code> Select color
<code>size</code> Select size (<code>1=small, 2=medium, 3=large</code>)
This command is closed with <code>CR</code> (carriage return), resetting the horizontal print position to <code>0</code>. After the last image data the page is printed with <code>FF</code> (form feed). For the nozzlelist see <code>createnozzlelist</code>, 5.6 on the following page</td></tr>
</table>

<table>
<tr><td>Syntax</td><td colspan="2"><code>ESC_i_matrix(color, matrix, spacing=3, size=1)</code></td></tr>
<tr><td rowspan="5">Parameters</td><td>Name</td><td>Type</td></tr>
<tr><td><code>color</code></td><td>hexadecimal byte</td></tr>
<tr><td><code>matrix</code></td><td>2D list or array</td></tr>
<tr><td><code>spacing</code></td><td>integer</td></tr>
<tr><td><code>size</code></td><td>integer</td></tr>
<tr><td>Description</td><td colspan="2">See section 6.5 for more information.
Creates the raster image data to print the data specified in a matrix using the selected nozzles (color) at a specified location
Parameter description:
<code>color</code> Select a color (group of nozzles)
<code>matrix</code> matrix containing (0, 1, 2, 3)
<code>spacing</code> Sets the horizontal spacing between the droplets (3 is approx. equal horizontal and vertical spacing, vertical spacing always 1/120 inch)
<code>size</code> Specify a size, if the matrix contains a 2 or 3, this will override the size setting, and print the size specified in the matrix. Matrix elements that are 1 will be printed with the specified size argument.
The specified matrix must be a 2D list, with the nested lists containing equal or less elements than the number of nozzles of a nozzle group. The number of nozzles in a group can be found using the parse script on a normal file send to the file printer. For the Epson SX235W, the 90 black nozzles are divided in three groups of 30, meaning larger patterns can be printed by dividing the pattern in three matrices.</td></tr>
</table>

5.6 Python nozzle select functions

Syntax	`createnozzlelist(nozzles,activen,spacing,firstnozzle=1)`	
Parameters	Name	Type
	`nozzles`	integer
	`activen`	integer
	`spacing`	integer
	`firstnozzle`	integer
Description	Creates a list containing ones and zeros with length `nozzles` (the number of nozzles of the printer). The `activen` parameter specifies the number of active nozzles (represented by a `1` in the list) and the `spacing` parameter specifies the number of non active nozzles (represented by `0`) between the active nozzles. The `firstnozzle` parameter sets the first active nozzle in the list (nozzle numbering starts at `0`).	
Example	`>>> createnozzlelist(10,3,1,2)` gives: `[0, 0, 1, 0, 1, 0, 1, 0, 0, 0]`	

Syntax	`createnozzlelistsp(nozzles,nozzlelist,firstnozzle = 1)`	
Parameters	Name	Type
	`nozzles`	integer
	`nozzlelist`	list containing integers
	`firstnozzle`	integer
Description	Creates a list containing ones and zeros with length `nozzles` (the number of nozzles of the printer). The `nozzlelist` parameter specifies the active nozzles (represented by a `1` in the list). The needed list contains the numbers of the active nozzles. The `firstnozzle` parameter shifts the nozzle numbering (default nozzle numbering starts at `0`).	
Example	`>>> createnozzlelistsp(10,[0,1,5],0)` gives: `[1, 1, 0, 0, 0, 1, 0, 0, 0, 0]`	

5.7 Examples

To show how the different functions can be combined to create a `prn` file the printer understands, a couple of example are provided. Using these examples one should be able to create custom files with specific needs. The code provided below shows how the print location is set and how to load header, body and footer data.

```
 1 ## Import modules
 2 import binascii
 3 from hex_functions import *
 4 from esc_functions import *
 5 
 6 ## Set dot specifications
 7 x = 5.5         # inches
 8 y = 3           # inches
 9 size = 1        # small droplet
10 an = 1          # dispensing nozzle
11 
12 ## Load printer parameters (Epson Stylus SX235W)
13 # unit parameters
14 pmgmt = 720
15 vert = 720
16 hor = 5760
17 m = 5760
18 nozzles = 30
19 # set nozzle row numbers
20 black = b’\x00’
21 black2 = b’\x05’
22 black3 = b’\x06’
23 cyan = b’\x02’
24 magenta = b’\x01’
25 yellow = b’\x04’
26 # select dot size
27 d = b’\x11’
28 # set page method ID
29 printid = b’\x20’)
30 # load header and footer data
31 header = load_prn_file(’sx235w-header.prn’)
32 footer = load_prn_file(’sx235w-footer.prn’)
33 
34 ## Create body data
35 body = ESC_Graph() + ESC_Units(pmgmt,vert,hor,m) + ESC_Kmode() + \
36 ESC_imode() + ESC_Umode(unim) + ESC_edot(d) + ESC_Dras() + \
37 ESC_C(pmgmt) + ESC_c(pmgmt) + ESC_S(pmgmt) + ESC_m(printid)
38 
39 ## Create image rasterdata
40 # Insert required image data:
41 # rasterdata
42 
43 ## Combine data
44 total = header + body + rasterdata + footer
45 
46 ## save prn file
47 filename = ’singlesmalldrop.prn’
48 save_prn_file(total,filename)
49 print(’DONE!’)
```

The image data still needs to be specified. In the following sections some examples are shown that can be inserted on `line 41` in the code. The `rasterdata` has to end with a form feed (FF, in Python `b'\0c'`) to let the printer know the page has ended. The examples can be combined to create every possible image.

Image data single dot

To create a single dot at the set location the code below needs to be inserted. The rasterdata has to end with a form feed (FF, in Python `b'\0c'`) to let the printer know the page has ended.

```python
nozzlelist = createnozzlelist(nozzles,1,0,an)
rasterdata = ESC_v(pmgmt,y) + ESC_dollar(hor,x) + ESC_i_nrs(nozzlelist,black,size) + b’\x0c’
```

Image data `n ∗ m` raster

To create a `n ∗ m` first the horizontal and vertical spacing has to be specified. The horizontal spacing can be set by using the ESC ($command and the vertical spacing can be set by creating a nozzlelist with `dy` inactive nozzles between the active nozzles. The nozzles for the Epson Stylus SX235W are spaced 1/120 inch ≈ 211.667 µm, depending on the geometry of the printhead.

```python
n = 10              # number of horizontal dots
m = 5               # number of vertical dots
dx = 250/25400      # set horizontal spacing to 250 um
dy = 1              # vertical spacing of 1 non active nozzle

nozzlelist = createnozzlelist(29,m,dy,1)
raster = b’’
for k in range(n):
  raster += ESC_dollar(hor,(x+dx*k)) + ESC_i_nrs(nozzlelist,black,size1)

rasterdata = ESC_v(pmgmt,y) + raster + b’\x0c’
```

Image data 10 drops over each other

Another possibility to have more freedom in the drop size is to let the printer dispense multiple droplets on top of each other. This can be done by repeating the proces for one droplet multiple times:

```python
nozzlelist = createnozzlelist(nozzles,1,0,an)
raster = b’’
for k in range(10):
  raster += ESC_dollar(hor,x) + ESC_i_nrs(nozzlelist,black,size1)

rasterdata = ESC_v(pmgmt,y) + raster + b’\x0c’
```

6 ESC/P2 Command manual

Some of the most relevant ESC/P2 commands will be discussed in this section. The description of the commands is adapted from the Programming guide published by Epson.[1] For some commands, specific pages of this guide will be referred for a more detailed explanation.

6.1 ESC/P2 command list

After the data is gathered with the commands described in section 2.1, the ESC/P2 file can be studied. The meaning and the function of the oft-recurring commands are described in this section. The commands discription is based on the ESC/P2 programming guide.[1]
Note that Epson printers only understand hexadecimal values. Below, equations are calculated in decimals. Two digits in hex equals 1 byte and 1 byte equals 8 bits.
Almost every code has an initialisation and thereafter some values that define the output.
The initialisation contains nL and nH. These values show how many bytes will follow after the initialisation part.
The number of bytes can be calculated as follows:
nL = MOD(bytes to follow/256)
nH = INT(bytes to follow/256)
For example: If nL=01H and nH=00H, means that 1 byte of data will follow.

6.2 Selects graphics mode ESC (G nL nH m

ESC (G nL nH m	version 1.1
Name	Sets graphics mode
Format	1BH, 28H, 47H, nL, nH, m
Description	nL=01H, nH=00H. m=01H or 31H. This commands shifts the code to graphics mode. 1) if m has any value other than above, this command is ignored. 2) The page management coordinate system and the position management coordinate system are set by taking the printing position in the Y direction at the time of setting as the origin on the Y-axis. This coordinate systems are shown in section 6.16 on page 29. 3) The printing position in the X direction is set to the origin upon the X-axis.

6.3 Set unit ESC (U nL nH P V H mL mH

ESC (U nL nH P V H mL mH version 1.1

Name	Set unit
Format	1BH, 28H, 55H, nL, nH, P, V, H, mL mH

Description	nL=05H, nH=00H.
	P, V and H are linked to Page management units, Vertical position units and Horizontal position units respectively.
	This command sets the units in the horizontal, vertical and page management. P=V=H. In order to calculate the units, first m has to be defined:
	m=(mH*256 + mL)={90,120,180,360,720,1440,2880,5760}
	P=m/{90,120,180,360,720,1440,2880}
	V=m/{90,120,180,360,720,1440,2880,5760}
	H=m/{90,120,180,360,720,1440,2880,5760}
	If we have for example: ESC (U 05 00 08 08 08 80 16 [hexadecimal]
	m=(22*256 + 128)=5760 [decimal]. P, V and H equals 08H:
	So 8=5760/**720**. That means that the unit in vertical, horizontal and page management is set to 1/720 inch. One step on the paper means a step of 1/720 inch ≈ 0.0353 mm.

6.4 Monochrome mode / Color mode selection ESC (K nL nH m n

ESC (K nL nH m n version 1.1

Name	Monochrome mode / Color mode selection
Format	1BH, 28H, 4BH, nL, nH, m, n

Description	nL=02H, nH=00H, m=00H,
	n=00H: Default mode(color)
	n=01H: Monochrome mode
	n=02H: Color mode

6.5 Transfer raster image ESC i r c b nL nH mL mH d1.....dk

ESC i r c b nL nH mL mH version 1.1

Name	Trasnfer raster image
Format	1BH, 69H, r, c, b, nL, nH, mL, mH,

Description	r=00H, 01H, 02H, 04H, 05H, 06H
	c=00H, 01H
	b=01H, 02H

r: color of ink:

01H:magenta, 02H:cyan, 04H:yellow, 00H:black1, 05H:black2, 06H:black3. Black1,2,3 refers to the first, second or third set of black nozzles used. Note: values of r will differ for other types of printers. This values of r are used for the Epson Stylus SX235W.

c: compression method:

00H:non-compressed

01H:Run Length Encoding (See page 49 in the Epson programming guide for further explanation.[1])

b: bit length required for each pixel of image data:

01H: 1bit/pixel

For every 1 bit of data:

0 no dot

1 a normal sized dot for the current dpi

02H: 2bits/pixel

For every 2 bits of data:

00 no dot

01 small dot

10 medium size dot

11 large size dot

This will be printed at the pixel location for those 2 bits.

For example, if we have data of one byte: 00011011, the printer will create 4 pixels of no dot, small dot, medium dot, large dot respectively.

nL, nH: Horizontal byte count, according to the following formulas:

nH=INT(horizontal byte count/256)

nL=MOD(horizontal byte count/256)

Number of dots per horizontal row=(horizontal byte count)*(4 pixels per byte)

Note: The formula above is only valid if b=02H.

mL, mH: Vertical dot count (rows of dot graphics) according to the following formulas:

mH=INT(vertical dot count/256)

mL=MOD(vertical dot count/256)

The vertical dot count is the number of nozzles in a column in the printhead, that is for the Epson Stylus SX235W 29 nozzles.

6.6 Turn unidirectional mode on/off ESC U n

ESC U n version 1.1

Name	Turn unidirectional mode on/off
Format	1BH, 55H, n

Description	The value n selects the printing direction:
	n=00H or 30H: Selects bi-directional printing
	n=01H or 31H: Selects unidirectional printing (0 to 80 column)
	n=02H or 32H: Selects automatic printing direction control
	n=03H or 33H: Selects unidirectional printing (80 to 0 column)
	Printers are often using bi-directional printing (00H). Bi-directional printing means that the printhead can dispense droplets in a line from left to right and from right to left.

6.7 Selects dot size ESC (e nL nH m d

ESC (e nL nH m d version 1.1

Name	Selects dot size
Format	1BH, 28H, 65H, nL, nH, m, d

Description	nL=02H, nH=00H, m=00H, d=00H, 10H, 11H, 12H, 13H
	The parameter d gives a certain dot size or a different printing quality.
	d=00H: VSD1 1bit(for DOS)
	d=10H: Economy 2bit
	d=11H: VSD1 2bit
	d=12H: VSD2 2bit
	d=13H: VSD3 2bit
	The different printing qualities together with the specifications are given in section 6.17 on page 30.
	Note: This print qualities are given for the Epson Stylus SX600FW. When using another printer this may differ. VSD1 is normally the most common used printing quality. When printing with VSD2 or VSD3, the quality of the print will increase.

6.8 Set the raster image resolution ESC (D nL nH rL rH v h

ESC (D nL nH rL rH v h version 1.1

Name	Set the raster image resolution
Format	1BH, 28H, 44H, nL, nH, rL, rH, v, h
Description	nL=04H, nH=00H The raster image resolution will be: Vertical resolution: (rH*256 + rL)/v dpi Horizontal resolution: (rH*256 + rL)/h dpi If we have for example ESC (D 04 00 40 38 78 28, rL=64, rH=56, v=120 and h=40 in decimals. The vertical resolution will be 14400/120 = 120 dpi The horizontal resolution will be 14400/40 = 360 dpi These values are confirmed by section 6.17 on page 30.

6.9 Set page length in defined unit ESC (C nL nH m1 m2 m3 m4

ESC (C nL nH m1 m2 m3 m4	version 1.1
Name	Set the page length in defined units of section 6.3 on page 24
Format	1BH, 28H, 43H, nL, nH, m1, m2, m2, m3
Description	nL=04H, nH=00H The page length is set to (m2*256 + m1)*(page management value)*25.4mm

6.10 Set page format ESC (c nL nH t1 t2 t3 t4 b1 b2 b3 b4

ESC (c nL nH t1 t2 t3 t4 b1 b2 b3 b4	version 1.1
Name	Set page format
Format	1BH, 28H, 63H, nL, nH, t1, t2, t3, t4, b1, b2, b3, b4
Description	nL=08H, nH=00H t means the top and b means the bottom. The origin of the Y axis of the position management coordinate systems shown in section 6.16 on page 29 is set to: (t4*256*3 + t3*256*2 + t2*256 + t1) * (defined unit in section 6.3 on page 24) from the origin on the Y axis of the page management coordinate system. The bottom margin is set at a position spaced in the positive downwards direction to: (b4*256*3 + b3*256*2 + b2*256 + b1) * (defined unit in section 6.3) from the origin on the Y axis of the position management coordinate system.

6.11 Set paper dimensions ESC (S nL nH w1 w2 w3 w4 l1 l2 l3 l4

ESC (S nL nH w1 w2 w3 w4 l1 l2 l3 l4	version 1.1
Name	Set paper dimensions
Format	1BH, 28H, 53H, nL, nH, w1, w2, w3, w4, l1, l2, l3, l4
Description	nL=08H, nH=00H w means the width and l means the lenght. The paper length is defined from the top-edge to the bottom-edge and the paper width is defined from the left-egde to the right-egde in defined unit. The paper length and width are defined by the following formula: Physical paper length = (l4*256*3 + l3*256*2 + l2*256 + l1) * (defined unit in section 6.3 on page 24) Physical paper width = (w4*256*3 + w3*256*2 + w2*256 + w1) * (defined unit in section 6.3)

6.12 Set print method ID ESC (m n

ESC (m n	version 1.1
Name	Set print method ID
Format	1BH, 28H, 6DH, nL, nH, n
Description	nL=01H, nH=00H n= 12H, 13H, 20H, 21H, 22H, 23H, 24H, 25H, 30H, 32H, 33H, 34H, 50H, 51H, 52H, 53H, 71H, 72H, A0H The print mode is selected according to the values of n. Common used values of n for black ink are shown in section 6.18 on page 30. The missing values of n in section 6.18 on page 30 are used for different types of photo paper media. This values of n are rarely used.

6.13 Set relative vertical print position ESC (v nL nH m1 m2 m3 m4

ESC (v nL nH m1 m2 m3 m4	version 1.1
Name	Set relative vertical print position
Format	1BH, 28H, 76H, nL, nH, m1, m2, m3, m4
Description	nL=04H, nH=00H The printing position in the Y direction is set to positive: (m4*256*3 + m3*256*2 + m2*256 + m1) * (relative vertical print position value) from the present Y printing position. The first ESC (v command measures downwards from the top of the page.

6.14 Set absolute horizontal print position ESC ($ nL nH m1 m2 m3 m4

ESC ($ nL nH m1 m2 m3 m4	version 1.1
Name	Set absolute horizontal print position
Format	1BH, 28H, 24H, nL, nH, m1, m2, m3, m4
Description	nL=04H, nH=00H The printing position in the positive X direction (left to right) is set to: (m4*256*3 + m3*256*2 + m2*256 + m1) * (horizontal units set in section 6.3 on page 24) from the origin (the left margin position, see section 6.16 on the next page) on the X axis of the position management coordinate system.

6.15 Select MicroWeave printing mode ESC (i 01 00 n

ESC (i 01 00 n version 1.1

Name Select MicroWeave printing mode

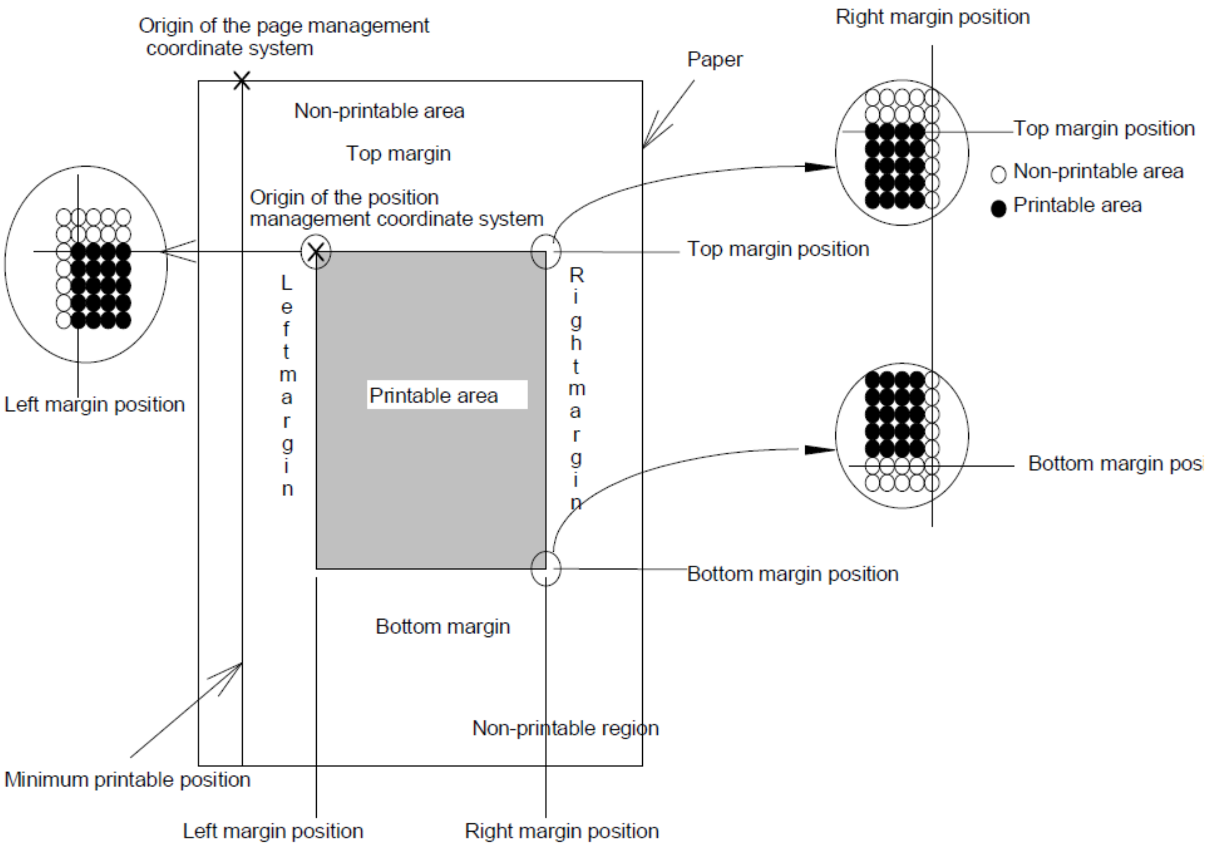
Format 1BH, 28H, 69H, 01H, 00H, n

Description n=00H, 01H, 30H, 31H

Selects / deselects the MicroWeave mode. The MicroWeave mode is an old method for accurate printing. The command is for newer printers useless, however it will show up in the parse -V script. There is little known about this mode and what the meaning of n is.

Note: when sending a code without this command to the Espon Stylus SX600FW and the SX235W, it will not affect the output.

6.16 Coordinate systems for a single sheet of paper[1]



6.17 Different quality levels of printing[1]

Print density			Dot size	Raster command density	ESC (D Setting horizontal	ESC (D Setting vertical	ESC i setting transfer raster image	ESC (e setting dot size	Remarks
Plain paper	Special paper	(Horizontal * Vertical)		(H * V)	h /r	v/ r	mH*256+mL	n2	-
Draft 1 (Fast Eco)		360dpi * 120dpi	EcoFnomy	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	10H	Color
Draft 2 (Eco)		360dpi * 120dpi	Economy	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	10H	Color
Draft 3 (Fast Eco)		360dpi * 360dpi	Economy	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	10H	Black
Draft 4 (Eco)		360dpi * 360dpi	Economy	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	10H	Black
Normal 1		360dpi * 360dpi	VSD1	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	11H	Black
Normal 2		360dpi * 360dpi	VSD1	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	11H	Color
	Fine 1	360dpi * 720dpi	VSD1	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	11H	
Fine 2		360dpi * 720dpi	VSD2	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	12H	
Photo 1		720dpi * 720dpi	VSD3	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	13H	
	Photo 2	720dpi * 720dpi	VSD2	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	12H	
	Best Photo	1440dpi * 720dpi	VSD3	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	13H	
	Photo RPM	5760dpi * 1440dpi	VSD3	360dpi * 120dpi 2bit	4/1440	12/1440	Max 128	13H	

6.18 Recommended setting modes (Black) for Windows[1]

Media	Mode	Print quality	Resolution dpi	Bi-directional printing	Dot size ESC (e	ESC (m		
						1*	2*	3*
Plain papers	Draft	Draft3	360*120	ON	10H	21H	24H	24H
	&Text	Normal1	360*360	&ON/OFF	11H	22H	25H	25H
	Text&Image	Fine2	360*720	&ON/OFF	12H	33H	34H	34H
	Photo	Photo1	720*720	&ON/OFF	13H	50H	53H	53H
	Best Photo	Photo1	720*720	ON/&OFF	13H	50H	53H	53H

*1 Standard

*2 Double-sides 1st side

*3 Double-sides 2nd side

&: Default

References

[1] Seiko Epson Corporation, *Programming guide for 4 Color EPSON Ink Jet Printer (Level 1)*, 2011.

[2] B. Henderson and J. Poskanzer, *PPM - Netpbm color image format*, `http://netpbm.sourceforge.net/doc/ppm.html`.