The EAN barcodes by TEX

Petr Olšák

Abstract. In this article, we describe the algorithm for the transformation from the EAN 13 code (13 digit number) to the barcode (the sequence of bars and spaces) and we show the implementation of this algorithm to the macro language of TEX. The drawing of the bars is realized by TEX primitive `\vrule`. Some data from the norm for the EAN barcodes (tolerances and so on) are presented too. The corresponding TEX macro is available on CTAN.

I have prepared my first book about TEX written in Czech [3]. My interest in preparing the book didn't end by sending the manuscript or the type matter to the publisher because the publisher is our CSTUG (Czechoslovak TEX users group). I made the cover design of the book, I worked on the distribution problems like getting the ISBN, and so on.

When I got the ISBN (International Standard Book Number), I converted it to the EAN 13 (European Article Numbering) and I took concern about the barcode for this number, because it is commonly used on the book covers. I found out that it would be very expensive to let the commercial firms make the barcode. On the other hand, using TEX to produce the barcodes is a very natural application of this program because of its high accuracy and its algorithmic macro language. To find the description of the conversion algorithm with 13 digits on the input and the barcode metrics on the output was the only problem. This algorithm is described in [1].

The transformation from the ISBN to the EAN is simple. The ISBN is a 10 digit number. The dashes between digits divide the ISBN into the fields (country-publisher-number-checksum) and (essentially) can be ignored. First we write three new constant digits (978) to the front of the ISBN number. Next we compute a new check sum digit (the last one). The algorithm for computing the ISBN checksum is different from the one for computing the EAN checksum. For EAN, first we need to compute the sum of digits on the even positions. Let the sum be e. Next we compute the sum of digits on the odd positions (without the checksum digit). Let the sum be o. We evaluate the expression $3 \times e + o$. The difference of the result to the next modulo-10 number is the check sum digit. For example the TEXbook hard cover [2] has its ISBN 0-201-13447-0 (0: country USA, 201: publisher Addison Wesley, 13447: internal book number assigned by publisher, 0: the check sum digit). We write three constant digits to the front and remove the checksum digit to obtain 978020113447?. Now $e = 7 + 0 + 0 + 1 + 4 + 7 = 19$ and $o = 9 + 8 + 2 + 1 + 3 + 4 = 27$. The difference of $3 \times 19 + 27 = 84$ and 90 is 6 and this is the check sum digit. We can divide the result by dashes into 6 digit fields (only for easier reading) and the result is 9-780201-134476.

The transformation from the EAN number to the barcode metric is more complicated. The first digit is 9 for books, but it is different for other kinds of goods. This digit doesn't have its own field in the barcode but it influences the algorithm for the transformation of the next digits to their fields. The widths of the bars or white spaces between the bars are multiples of the basic so called "module X". The size of the module X varies for different SC norms (see below), but the basic size is 0.33 mm. Each digit from the positions 12 to 1 is transformed to the field of the 7X module width. This field by definition contains two bars and two white spaces. The "start mark" of the 3X module width (1X bar, 1X space and 1X bar) is appended before the digit from the 12-th position. The same "stop mark" (3X module width) is appended after the last digit and so called "separator mark" of 5X module width (1X space, 1X bar, 1X space, 1X bar and 1X space) is placed between digits on the 7-th and 6-th positions. The "mark" bars are 5X longer than the bars from the digits.

It is easy to see, that the total length of the EAN barcode is 95X. Further we have to consider the 11X white space left to the code and 7X white space right to the code. These are the minimal white "margins", which are important for the barcodes on the color background. The total number of bars is 30.

Each digit is transformed into two bars in its 7X size field by one of the following tables (A, B and C).

Zero in the table stands for the white module (of 1X size) and one means the black module. For example, the digit 4 is converted to 1X space, 1X bar, 3X space and 2X bar by table A and to 2X space, 3X bar, 1X space and 1X bar by table B. Notice that all tables convert the digit into exactly two spaces and two bars and that the converted field starts with the space if table A or B is used, and with the bar if table C is used.

	tab. A	tab. B	tab. C
0	0001101	0100111	1110010
1	0011001	0110011	1100110
2	0010011	0011011	1101100
3	0111101	0100001	1000010
4	0100011	0011101	1011100
5	0110001	0111001	1010000
6	0101111	0000101	1010000
7	0111011	0010001	1000100
8	0110111	0001001	1001000
9	0001011	0010111	1110100

Tables A, B and C.

The digits on positions 6 to 1 are transformed by table C under any circumstance. The digits on positions 12 to 7 are transformed by table A or B. The choice depends on the value of the digit on the 13-th position, as described in the table "The dependence on 13-th digit".

13-th digit	12	11	10	9	8	7
0	A	A	A	A	A	A
1	A	A	B	A	B	B
2	A	A	B	B	A	B
3	A	A	B	B	B	A
4	A	B	A	A	B	B
5	A	B	B	A	A	B
6	A	B	B	B	A	A
7	A	B	A	B	A	B
8	A	B	A	B	B	A
9	A	B	B	A	B	A

The dependence on 13-th digit.

For example, if the digit on position 13 is 9 (our case for books), the digits on positions 12, 9 and 7 are transformed by table A and the ones on positions 11, 10 and 8 are transformed by table B.

Now we can show the TEX macro. First we load the special OCRb font for the printout of the EAN code in a human readable form. This printout is appended to the barcode. The METAFONT sources of these fonts are available on CTAN and they are made by Norbert Schwarz. I had to do one little correction in these sources: the command "`mode_setup;`" was added to the beginning of the file `ocrbmac.mf`.

```
\message{The EAN-13 barcodes macro. Copyright (C) Petr Olsak, 1995}
\font\ocrb=ocrb9       % for EAN in ``number form''
\font\ocrbsmall=ocrb7  % for ISBN
```

Next we declare some "variables":

```
\newcount\numlines \newcount\nummoduls  % number of bars and of moduls.
\newcount\numdigit \newcount\evensum \newcount\oddsum  % internal variables
\newdimen\X              % the module size X,
\newdimen\bcorr          % the bar correction (see bellow).
\newdimen\workdimen \newdimen\barheight   % internal variables
```

The main macro `\EAN` converts the 13 digit EAN number to the internal 60 digit number `\internalcode`. Each digit of the `\internalcode` represents the multiple of the X module size for either the white space or the bar. The order of digits is the same as the order of spaces and bars in the code. The odd positions in the `\internalcode` (from left) stand for the white spaces and the even ones for the bars.

The usage of the macro is `\EAN 9-780201-134476`, for example. The presence of the "`-`" signs has no significance. The macro reads 13 digits and saves them in `\firstdigit`, `\frontdigits` and `\enddigits`. At this point, the macro converts the input into `\internalcode` using macros `\settabs`, `\usetabAB`, `\insertseparator` and `\usetabC`.

```
\def\internalcode{0111}             % Begin mark at start
\def\frontdigits{}                  % 12--7 digit of EAN
\def\EAN{\begingroup\EANscan}
\def\EANscan#1{\if#1-\let\next=\EANscan \else
    \advance\numdigit by1
    \ifnum\numdigit<13
      \ifodd\numdigit \advance\oddsum by #1 \else \advance\evensum by #1 \fi
      \let\next=\EANscan
      \ifnum\numdigit=1 \settabs#1\def\firstdigit{#1}\else
      \ifnum\numdigit<8 \usetabAB#1\edef\frontdigits{\frontdigits#1}\else
      \ifnum\numdigit=8 \insertseparator \A \usetabC #1\def\enddigits{#1}%
      \else             \usetabC#1\edef\enddigits{\enddigits#1}%
      \fi\fi\fi
    \else \testchecksum#1\usetabC#1\edef\enddigits{\enddigits#1}%
      \let\next=\EANclose
    \fi\fi \next}
```

The `\testchecksum` macro checks for the correctness of the last (check-sum) digit of the EAN.

```
\def\testchecksum#1{\multiply\evensum by3 \advance\evensum by\oddsum
    \oddsum=\evensum
    \divide\oddsum by10 \multiply\oddsum by10 \advance\oddsum by10
    \advance\oddsum by-\evensum \ifnum\oddsum=10 \oddsum=0 \fi
    \ifnum#1=\oddsum \else
    \errmessage{The checksum digit has to be \the\oddsum, no #1 !}\fi}
```

At the time of the `\EANclose` expansion, we close the `\internalcode` by the `\insertendmark`, next we write to the `log` the EAN number in the 13 digit form and in the internal 60 digit representation. The last action is to "run" the macro `\EANbox`, which makes the box with the barcode. The input parameter of this macro is the 60 digit `\internalcode`.

```
\def\EANclose{\insertendmark
    \wlog{EAN: \firstdigit\space\frontdigits\space\enddigits}%
    \wlog{EANinternal: \internalcode}%
    \expandafter\EANbox\internalcode..\endgroup}
```

How was the `\internalcode` made? The following macros give the answer to this question. These macros are the tables mentioned above rewritten to the macro language of TeX.

```
\def\A{\def\0{3211}\def\1{2221}\def\2{2122}\def\3{1411}\def\4{1132}%
  \def\5{1231}\def\6{1114}\def\7{1312}\def\8{1213}\def\9{3112}}
\def\B{\def\0{1123}\def\1{1222}\def\2{2212}\def\3{1141}\def\4{2311}%
  \def\5{1321}\def\6{4111}\def\7{2131}\def\8{3121}\def\9{2113}}
\def\settabs#1{\ifnum#1=0 \def\tabs{\A\A\A\A\A\A}\fi
               \ifnum#1=1 \def\tabs{\A\A\B\A\B\B}\fi
               \ifnum#1=2 \def\tabs{\A\A\B\B\A\B}\fi
               \ifnum#1=3 \def\tabs{\A\A\B\B\B\A}\fi
               \ifnum#1=4 \def\tabs{\A\B\A\A\B\B}\fi
               \ifnum#1=5 \def\tabs{\A\B\B\A\A\B}\fi
               \ifnum#1=6 \def\tabs{\A\B\B\B\A\A}\fi
               \ifnum#1=7 \def\tabs{\A\B\A\B\A\B}\fi
               \ifnum#1=8 \def\tabs{\A\B\A\B\B\A}\fi
               \ifnum#1=9 \def\tabs{\A\B\B\A\B\A}\fi}
```

```
49 \def\usetabAB#1{\expandafter\scantab\tabs\end \usetabC #1}
50 \def\scantab#1#2\end{#1\def\tabs{#2}} % The tab #1 is activated and removed
51 \def\usetabC#1{\edef\internalcode{\internalcode\csname#1\endcsname}}
52 \def\insertseparator{\edef\internalcode{\internalcode 11111}}
53 \def\insertendmark{\edef\internalcode{\internalcode 111}}
```

There is no need to define table C in the macro, because table C is exact "inverse" of table A. When we insert the separator (line 52 of the macro), the odd number of digits (namely 5) is appended to the `\internalcode`. This implies, that the parity of the black/white order is changed. Using the table `\A` is therefore sufficient for the transformation of the digits on the positions 6 to 1 (see line 19).

Now comes the most important part of our macro: creating the bars by TeX primitive `\vrule`. The internal macro `\EANbox` does this job. The macro reads the 60 digit `\internalcode` (ended by two dots) as its parameter. It scans two digits per step from the parameter (first digit: the white space, second digit: the black bar) and puts in the appropriate kerns and rules. Each couple of kern/rule is corrected by so called "bar correction". The norm recommends to make each rule thiner than what is exactly implied by the multiple of the X size. This recommendation is due to the ink behavior during the actual printing. For example for the offset process technology, it is recommended to reduce bar width by 0.020 mm. Of course, if the bar width is reduced, the white space must be enlarged by the same amount in order to save the global distance between bars.

The bars 1, 2, 15, 16, 29 and 30 have nonzero depth (5X) because these are the lines from the start, the separator and the stop marks. The height of the bars is 69.24 X in the normal case but it may be reduced, if the ISBN is appended to the top of the code. If the `\barheight` is zero, than the implicit height is used. Otherwise the `\barheight` is used. This feature gives the user the possibility to set the bar height individually.

```
54 \def\EANbox{\vbox\bgroup\offinterlineskip
55   \setbox0=\hbox\bgroup \kern11\X\EANrepeat}
56 \def\EANrepeat#1#2{\if#1.\let\next=\EANfinal \else\let\next=\EANrepeat
57   \advance\numlines by1
58   \advance\nummoduls by#1 \advance\nummoduls by#2
59   \workdimen=#1\X \advance\workdimen by \bcorr \kern\workdimen
60   \workdimen=#2\X \advance\workdimen by-\bcorr \vrule width\workdimen
61      \ifdim\barheight=0pt height 69.24242424\X \else height\barheight \fi
62      \ifnum\numlines=1    depth5\X\else  % the start mark
63      \ifnum\numlines=2    depth5\X\else
64      \ifnum\numlines=15   depth5\X\else  % the separator mark
65      \ifnum\numlines=16   depth5\X\else
66      \ifnum\numlines=29   depth5\X\else  % the end mark
67      \ifnum\numlines=30   depth5\X\else depth0pt \fi\fi\fi\fi\fi\fi
68   \fi\next}
```

The `\EANfinal` macro checks for the correctness of the scanned `\internalcode`. The number of the digits must be 60 and the sum of digits must be 95 (since 95X modules is the total). If the check fails, the `\internalerr` macro is activated. However this situation should never occur. This error indicates that some internal tables are wrong and/or the consistence of the macro is broken.

The `\vbox` is completed by the `\EANfinal`. The natural depth of the internal `\hbox` with the bars is 5X because that is the depth of the mark rules. We overwrite this depth by zero and append the human readable EAN number using the font `\ocrb`.

```
69 \def\EANfinal{\testconsistence
70   \kern7\X\egroup
71   \hbox{\ocrbsmall \kern10\X \ISBNnum}\kern1\X
72   \dp0=0pt \box0 \kern-1\X
73   \hbox{\ocrb\kern2\X\firstdigit\kern5\X \frontdigits\kern5\X \enddigits}
74   \egroup \global\barheight=0pt \gdef\ISBNnum{}}
75 \def\testconsistence{\ifnum\numlines=30\else\internalerr\fi
76   \ifnum\nummoduls=95\else\internalerr\fi}
77 \def\internalerr{\errmassage{Sorry, my internal tables are wrong, may be.}}
```

If the user writes the ISBN number using the macro `\ISBN` (`\ISBN 0-201-13447-0` for example), these data are appended to the top of the barcode and the height of the bars is reduced.

```
\barheight=0pt
\def\ISBNnum{}
\def\ISBN #1 {\def\ISBNnum{ISBN #1}\barheight=45.151515\X\relax}
```

Finally, we define the X module size and the bar correction.

```
\X=.33mm       % Basic size 100%, SC2 code
\bcorr=.020mm  % Bar-correction for offset process
\endinput
```

The macro was stored in the file `ean13.tex` and was tested in plain TeX through:

```
\input ean13
\nopagenumbers
\ISBN 80-901950-0-8  \EAN 978-80-901950-0-4   % Typograficky system TeX
\end
```

The output looks like:

ISBN 80-901950-0-8

9 788090 195004

The macro worked in LaTeX 2.09 as well. The LaTeX 2_ε was not tested.

At the end of this article we compare the tolerances described in the norm, the TeX accuracy and the possibilities of some output devices.

The X module size can vary. The macro above makes the EAN barcodes for the basic X module size of 0.33 mm. This size is described in the SC2 variant of the norm as the basic 100% size code. However the norm allows even some other sizes of the X module. One can change the parameter `\X` to obtain the other size of EAN code. Of course, then the size of the OCRb font must be changed too.

The allowed sizes of the X module are described in the table "The various sizes of X module".

The small sizes of the module X are recommended for the high quality output devices while the large sizes of X give the possibility to make the barcodes even on the low resolution output device.

Depending on the width of the module size X, the norm specifies three tolerance parameters. The parameter a specifies the tolerance for the bar width, the parameter b specifies the tolerance for the distance between edges (either left ones or right ones) of two consecutive bars and the parameter c specifies the tolerance for the width of the field for one digit (therefore for the 7X width). The table "The tolerances" describes these tolerances in micrometers (μm). I don't know, why the table column "X size" doesn't match with the previous table column "X size". Sorry, the norms are mysterious.

Now we can compare. Consider the basic 100% size (X module is 0.33 mm). The tolerance for the bar width is 101 μm, the TeX (in)accuracy is 0.0054 μm, the pixel size of the phototypesetter at 2400 dpi is approximately 10 μm and the recommended bar correction for the offset process is 20 μm. If we use the phototypesetter at 1200 dpi, the inaccuracy of its output is comparable to the bar correction for the offset process.

Depending on the inner `dvi` driver algorithm the TeX high accuracy may be lost and the tolerance parameters may be overcome. The `dvi` driver algorithms include one of two possible approaches to the "round" problem. The first approach is to position and round each rule from `dvi` individually. In the second approach, the `dvi` driver works only with rounded values (one pixel = one unit) *before* making the queue of kern, rule, kern, rule... In this case, the round-off error can accumulate and the parameter c can be overcome. But it seems to me that the barcode scanners can read the code better if the metrics of the consecutive bars and spaces is preserved instead of the global width.

As I observed, the `dvi` drivers usually round the rule width *up* to the pixel units and never *down*. The consequence of this feature is, that spaces tend to be one pixel smaller than the rules of (presumably) same width. Therefore I recommend to add one half of the pixel size to the bar correction, namely to the `\bcorr` register.

X size	norm	scaled	size incl. margins
0.264	SC0	0.800	29.83 × 21.00
0.270	SC0	0.818	30.58 × 21.53
0.281	SC0	0.850	31.70 × 22.32
0.297	SC1	0.900	33.56 × 23.63
0.313	SC1	0.950	35.43 × 24.94
0.330	SC2	1.000	37.29 × 26.26
0.346	SC2	1.050	39.15 × 27.58
0.363	SC3	1.100	41.02 × 28.29
0.379	SC3	1.150	42.88 × 30.20
0.396	SC4	1.200	44.75 × 31.51
0.412	SC4	1.250	46.61 × 32.82
0.429	SC5	1.300	48.48 × 34.14
0.445	SC5	1.350	50.34 × 35.45
0.462	SC5	1.400	52.21 × 36.76
0.478	SC5	1.450	54.07 × 38.08
0.495	SC6	1.500	55.94 × 39.39
0.511	SC6	1.550	57.80 × 40.70
0.528	SC7	1.600	59.66 × 42.01
0.544	SC7	1.650	61.53 × 43.33
0.561	SC7	1.700	63.39 × 44.64
0.577	SC7	1.750	65.26 × 45.96
0.594	SC8	1.800	67.12 × 47.26
0.610	SC8	1.850	68.99 × 48.58
0.627	SC8	1.900	70.85 × 49.90
0.643	SC8	1.950	72.72 × 51.20
0.660	SC9	2.000	74.58 × 52.52
0.700	SC10	2.120	79.05 × 55.67

The various sizes of X module.

I have heard that the EAN barcodes are successfully read from stickers printed by matrix printers with a very low resolution at module X size of 0.33 mm or comparably small. That would imply that the tolerances of the barcode scanners are usually much higher than those required by the norm.

References

[1] Adriana Benadiková, Štefan Mada and Stanislav Weinlich. *Čárové kódy, automatická identifikace (Barcodes, the Automatics Identification).* Grada 1994, 272 pp., ISBN 80-85623-66-8.
[2] Donald Knuth. *The TEXbook*, volume A of *Computers and Typesetting.* Addison-Wesley, Reading, MA, USA, 1986. ix+483 pp. Hard cover ISBN 0-201-13447-0.
[3] Petr Olšák. *Typografický systém TEX (Typesetting System TEX).* CSTUG 1995, 270 pp., ISBN 80-901950-0-8.

X size	$\pm a$	$\pm b$	$\pm c$
0.26	32	38	75
0.28	52	41	81
0.30	72	44	87
0.32	92	47	93
0.33	101	49	96
0.34	105	50	99
0.36	115	53	104
0.38	124	56	110
0.40	134	59	116
0.42	143	62	122
0.44	152	65	128
0.46	162	68	133
0.48	171	71	139
0.50	181	73	145
0.52	190	76	151
0.54	199	79	157
0.56	209	82	162
0.58	218	85	168
0.60	228	88	174
0.62	237	91	180
0.64	246	94	186

The tolerances.