

OPLx decapsulated

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We have an interest in emulation of YM3812, which is the OPL2 sound chip found in the Adlib and 8-bit Sound Blaster cards. A later derivative OPL3 is found in early 16-bit Sound Blasters. We sent one YM3812 and one YMF262 (OPL3) to MEFAS for decapsulation; the cost was around 90 USD each. They indicated that the chips would still be operational after decapsulation, but we had no need to test this. Looking at the revealed YM3812 die surface with a microscope turned out two ROM's.

The contents could be read bit-by-bit. The first ROM was a log-sin waveform table, containing one quarter of a sine wave, 256 samples long. The second ROM was an exponential table, 256 samples long. There were no other ROM's larger than 16 samples. This is strong evidence that YM3812 produces the sound without any multiplications, using for frequency modulated (actually phase modulated) synthesis the formula:

$$\text{out} = \exp(\log\sin(\text{phase2} + \exp(\log\sin(\text{phase1}) + \text{gain1})) + \text{gain2})$$

There was first some difficulty understanding the ROM's because they were compressed. Every second sample was stored as a difference value to the previous. Once this was understood, we were able to derive formulas that met our expectations and re-created the contents of the ROM tables exactly (yes, they used the same rounding and everything at Yamaha, back then when they created these tables).

Exponential table:

$$x = 0..255, y = \text{round}((\text{power}(2, x/256)-1)*1024)$$

When such a table is used for calculation of the exponential, the table is read at the position given by the 8 LSB's of the input. The value + 1024 (the hidden bit) is then the significand of the floating point output and the yet unused MSB's of the input are the exponent of the floating point output. Indeed, YM3812 sends the audio to the YM3014B DAC in floating point, so it is quite possible that summing of voices is done in floating point also.

Log-sin table:

$$x = 0..255, y = \text{round}(-\log(\sin((x+0.5)*\pi/256/2))/\log(2)*256)$$

This is the first (rising) quarter of sine wave. The rest can be constructed by flipping all the bits of x and/or by changing the sign of the samples.

We hope this will be useful for anyone writing a good emulator. Also, there are no extra ROM's on the YMF262 (OPL3), so the additional waveform is probably simply the exponential table.

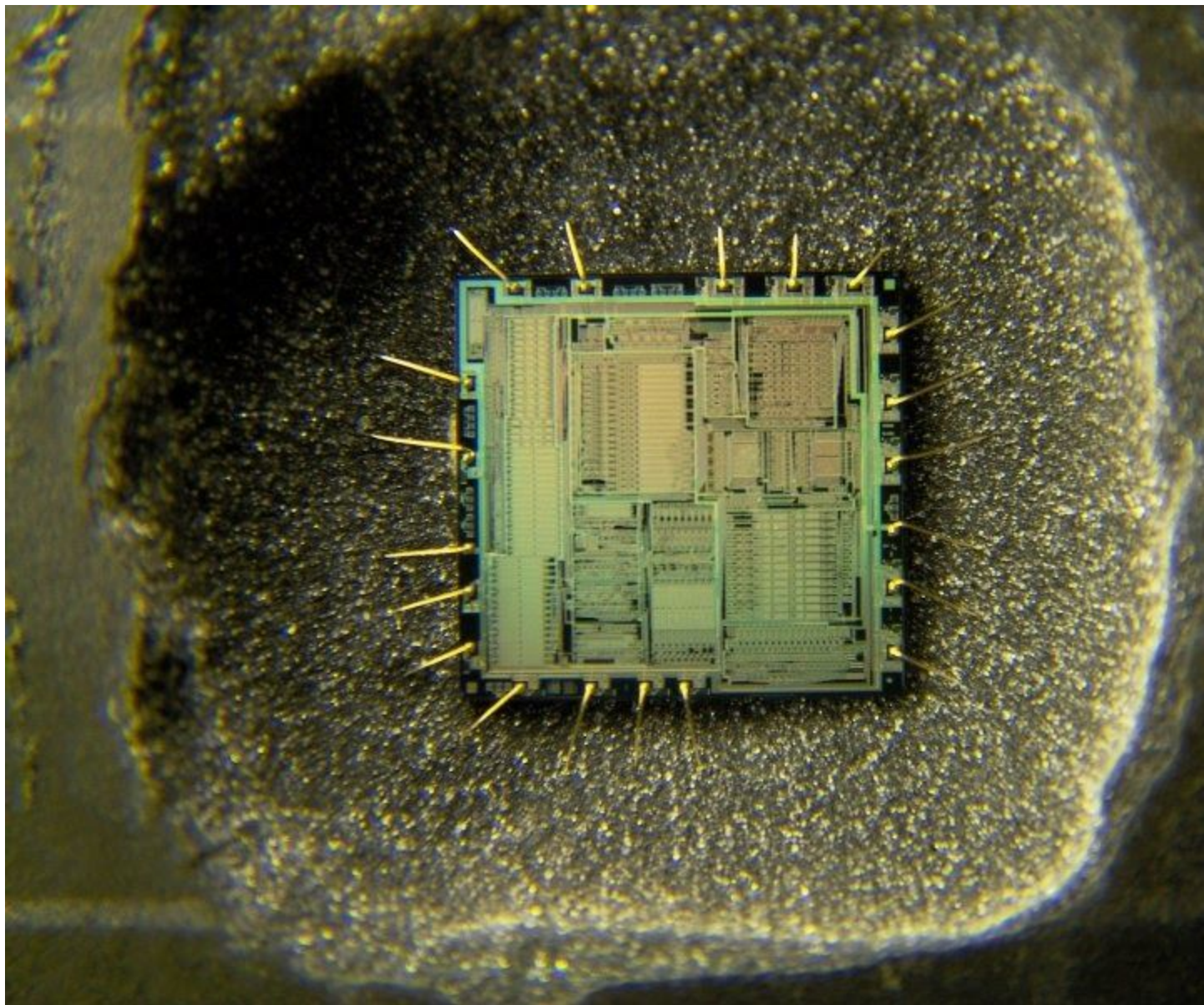


Figure 1. Decapsulated YM3812 (OPL2). The ROM's are the rectangular areas horizontally next to each other on the middle-right side.

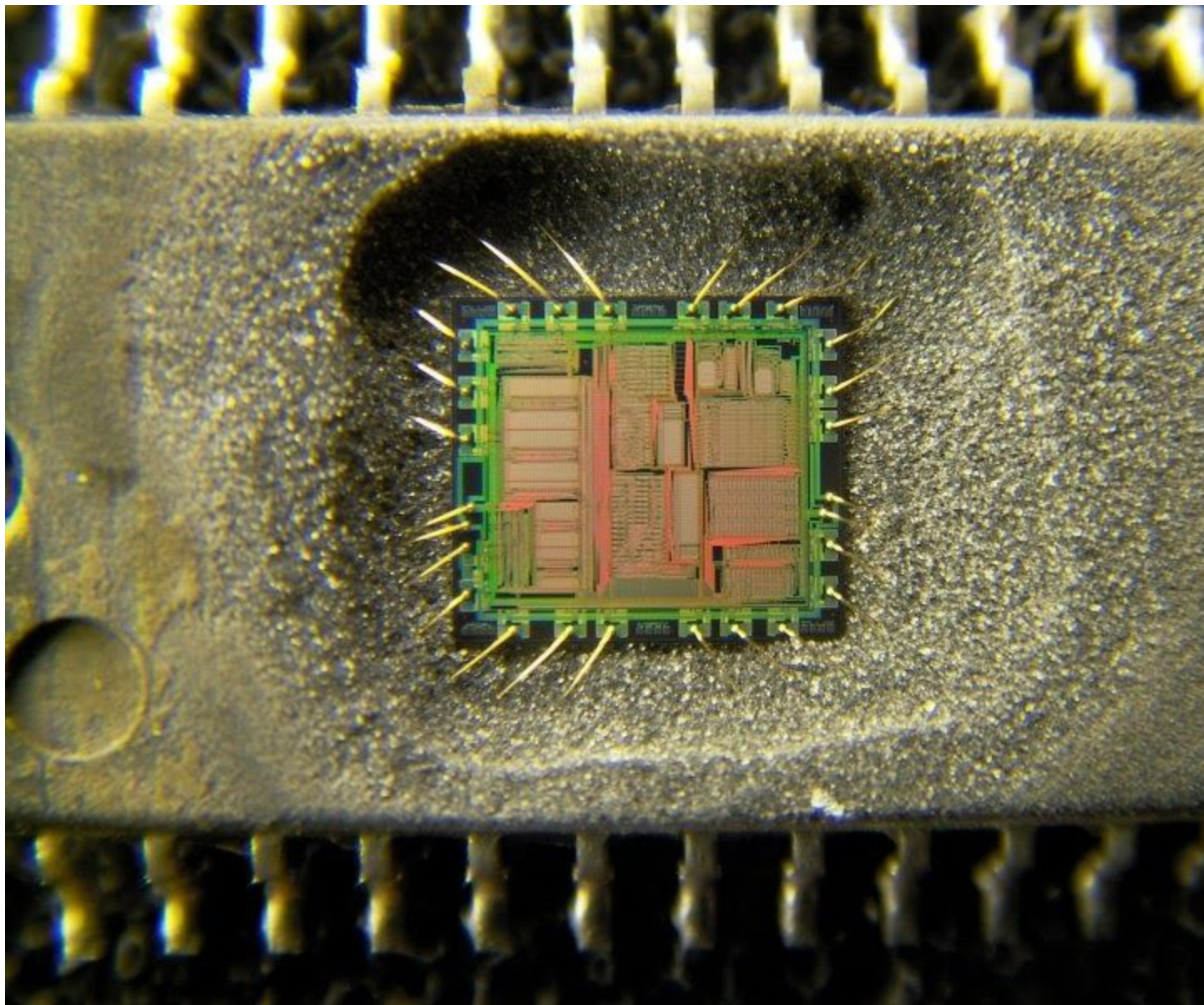


Figure 2. Decapsulated YMF262 (OPL3). The ROM's are the bright rectangular areas in the top-right corner.

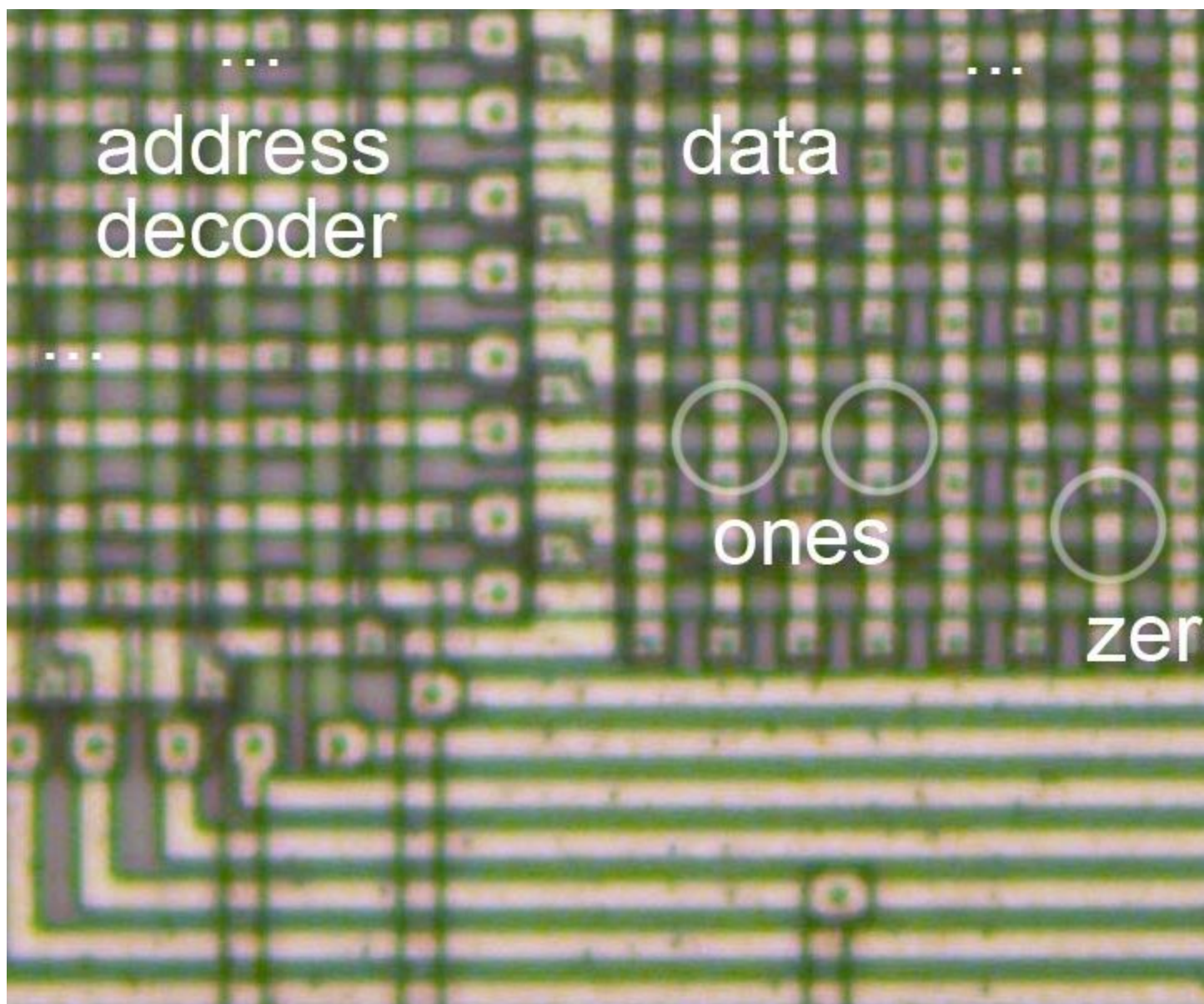


Figure 3. How a YM3812 ROM could be read.

Table I. The exponential table of YM3812 generated by $y = \text{round}((\text{power}(2, x/256)-1)*1024)$

x	y
0	0
1	3
2	6
3	8
4	11
5	14
6	17
7	20
8	22
9	25
10	28
11	31
12	34
13	37

14 40
15 42
16 45
17 48
18 51
19 54
20 57
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22 63
23 66
24 69
25 72
26 75
27 78
28 81
29 84
30 87
31 90
32 93
33 96
34 99
35 102
36 105
37 108
38 111
39 114
40 117
41 120
42 123
43 126
44 130
45 133
46 136
47 139
48 142
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51 152
52 155
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55 164
56 168
57 171
58 174
59 177
60 181
61 184
62 187
63 190
64 194
65 197
66 200
67 204
68 207
69 210
70 214
71 217
72 220
73 224
74 227
75 231
76 234
77 237
78 241
79 244

80 248
81 251
82 255
83 258
84 262
85 265
86 268
87 272
88 276
89 279
90 283
91 286
92 290
93 293
94 297
95 300
96 304
97 308
98 311
99 315
100 318
101 322
102 326
103 329
104 333
105 337
106 340
107 344
108 348
109 352
110 355
111 359
112 363
113 367
114 370
115 374
116 378
117 382
118 385
119 389
120 393
121 397
122 401
123 405
124 409
125 412
126 416
127 420
128 424
129 428
130 432
131 436
132 440
133 444
134 448
135 452
136 456
137 460
138 464
139 468
140 472
141 476
142 480
143 484
144 488
145 492

146 496
147 501
148 505
149 509
150 513
151 517
152 521
153 526
154 530
155 534
156 538
157 542
158 547
159 551
160 555
161 560
162 564
163 568
164 572
165 577
166 581
167 585
168 590
169 594
170 599
171 603
172 607
173 612
174 616
175 621
176 625
177 630
178 634
179 639
180 643
181 648
182 652
183 657
184 661
185 666
186 670
187 675
188 680
189 684
190 689
191 693
192 698
193 703
194 708
195 712
196 717
197 722
198 726
199 731
200 736
201 741
202 745
203 750
204 755
205 760
206 765
207 770
208 774
209 779
210 784
211 789

212 794
 213 799
 214 804
 215 809
 216 814
 217 819
 218 824
 219 829
 220 834
 221 839
 222 844
 223 849
 224 854
 225 859
 226 864
 227 869
 228 874
 229 880
 230 885
 231 890
 232 895
 233 900
 234 906
 235 911
 236 916
 237 921
 238 927
 239 932
 240 937
 241 942
 242 948
 243 953
 244 959
 245 964
 246 969
 247 975
 248 980
 249 986
 250 991
 251 996
 252 1002
 253 1007
 254 1013
 255 1018

Table II. The log-sin table of YM3812 generated by $y = \text{round}(-\log(\sin((x+0.5)\pi/256/2))/\log(2))*256$*

x y
 0 2137
 1 1731
 2 1543
 3 1419
 4 1326
 5 1252
 6 1190
 7 1137
 8 1091
 9 1050
 10 1013
 11 979
 12 949
 13 920
 14 894
 15 869
 16 846
 17 825

18 804
19 785
20 767
21 749
22 732
23 717
24 701
25 687
26 672
27 659
28 646
29 633
30 621
31 609
32 598
33 587
34 576
35 566
36 556
37 546
38 536
39 527
40 518
41 509
42 501
43 492
44 484
45 476
46 468
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48 453
49 446
50 439
51 432
52 425
53 418
54 411
55 405
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213 13
214 12
215 12

216 11
217 10
218 10
219 9
220 9
221 8
222 8
223 7
224 7
225 7
226 6
227 6
228 5
229 5
230 5
231 4
232 4
233 4
234 3
235 3
236 3
237 2
238 2
239 2
240 2
241 1
242 1
243 1
244 1
245 1
246 1
247 1
248 0
249 0
250 0
251 0
252 0
253 0
254 0
255 0