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:

out = exp(logsin(phase2 + exp(logsin(phase1) + gain1)) + 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 = round((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 = 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.

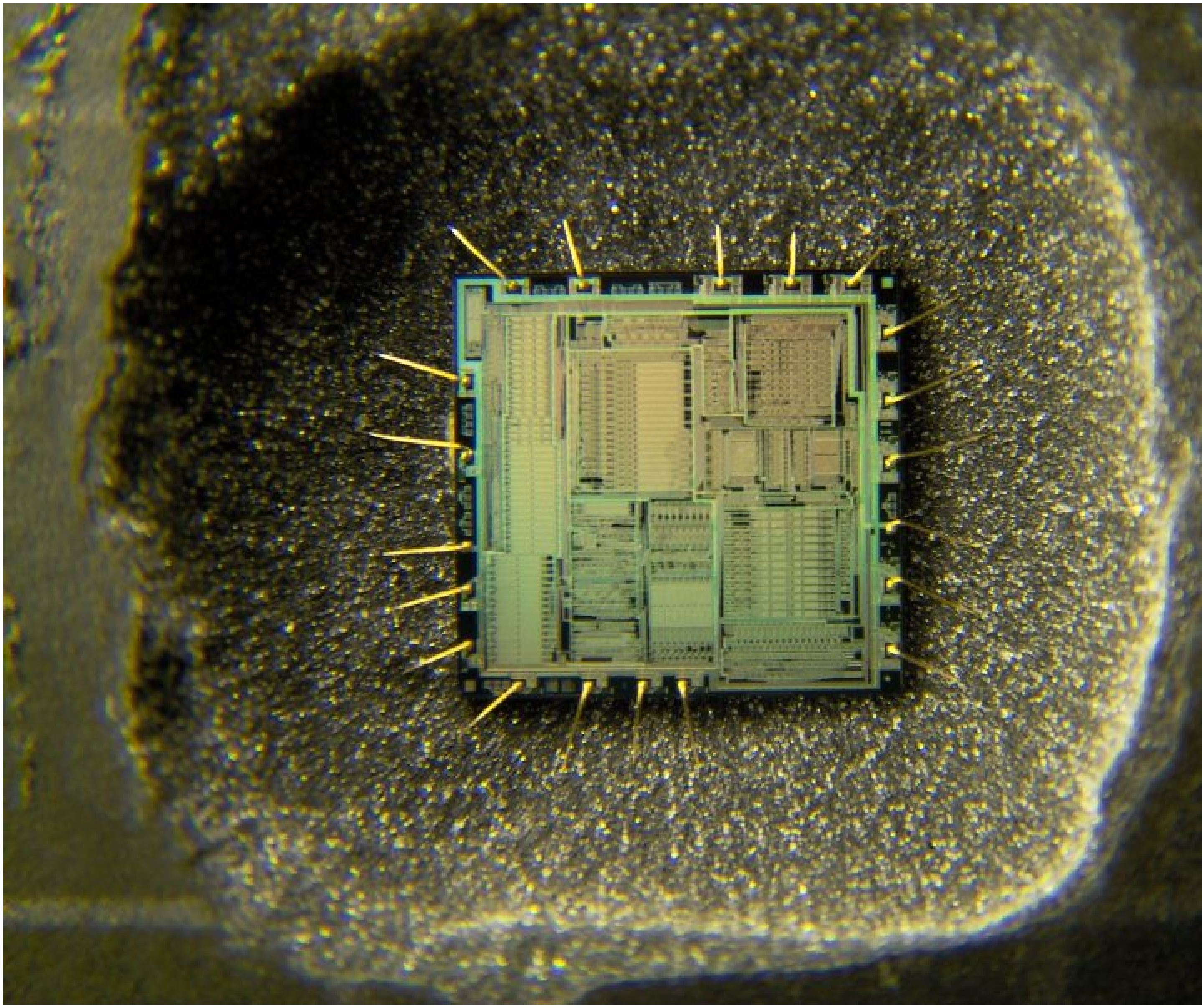

Figure 1. Decapsulated YM3812 (OPL2). The ROM's are the rectangular areas horizontally next to each other on the middle-right side.

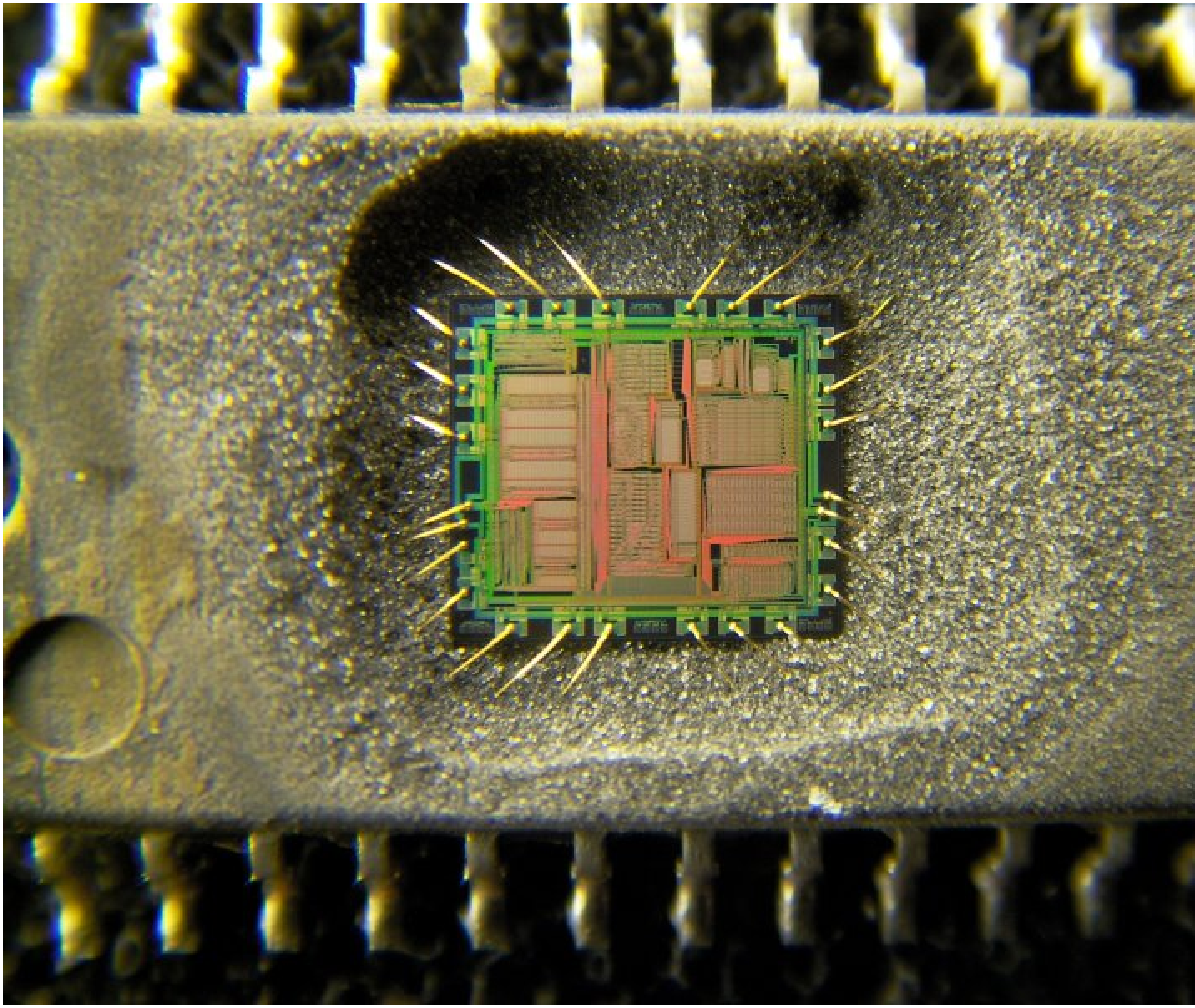

Figure 2. Decapsulated YMF262 (OPL3). The ROM's are the bright rectangular areas in the top-right corner.

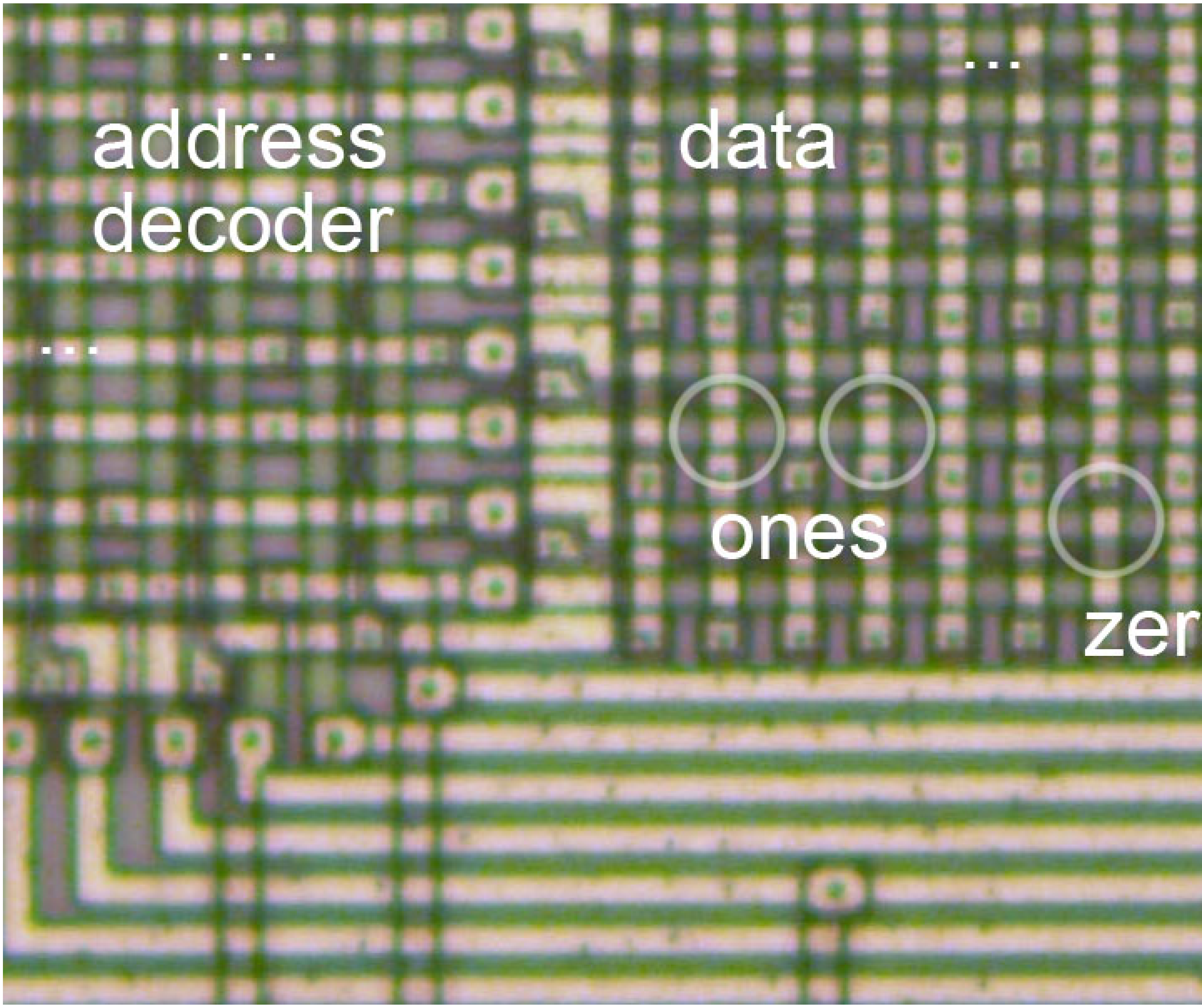

Figure 3. How a YM3812 ROM could be read.

*Table I. The exponential table of YM3812 generated by y = round((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
21 60
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
49 145
50 148
51 152
52 155
53 158
54 161
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 = 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
47	461
48	453
49	446
50	439
51	432
52	425
53	418
54	411
55	405
56	399
57	392
58	386
59	380
60	375
61	369
62	363
63	358
64	352
65	347
66	341
67	336
68	331
69	326
70	321
71	316
72	311
73	307
74	302
75	297
76	293
77	289
78	284
79	280
80	276
81	271
82	267
83	263
84	259

85	255
86	251
87	248
88	244
89	240
90	236
91	233
92	229
93	226
94	222
95	219
96	215
97	212
98	209
99	205
100	202
101	199
102	196
103	193
104	190
105	187
106	184
107	181
108	178
109	175
110	172
111	169
112	167
113	164
114	161
115	159
116	156
117	153
118	151
119	148
120	146
121	143
122	141
123	138
124	136
125	134
126	131
127	129
128	127
129	125
130	122
131	120
132	118
133	116
134	114
135	112
136	110
137	108
138	106
139	104
140	102
141	100
142	98
143	96
144	94
145	92
146	91
147	89
148	87
149	85
150	83

151	82
152	80
153	78
154	77
155	75
156	74
157	72
158	70
159	69
160	67
161	66
162	64
163	63
164	62
165	60
166	59
167	57
168	56
169	55
170	53
171	52
172	51
173	49
174	48
175	47
176	46
177	45
178	43
179	42
180	41
181	40
182	39
183	38
184	37
185	36
186	35
187	34
188	33
189	32
190	31
191	30
192	29
193	28
194	27
195	26
196	25
197	24
198	23
199	23
200	22
201	21
202	20
203	20
204	19
205	18
206	17
207	17
208	16
209	15
210	15
211	14
212	13
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