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NORSAR

ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

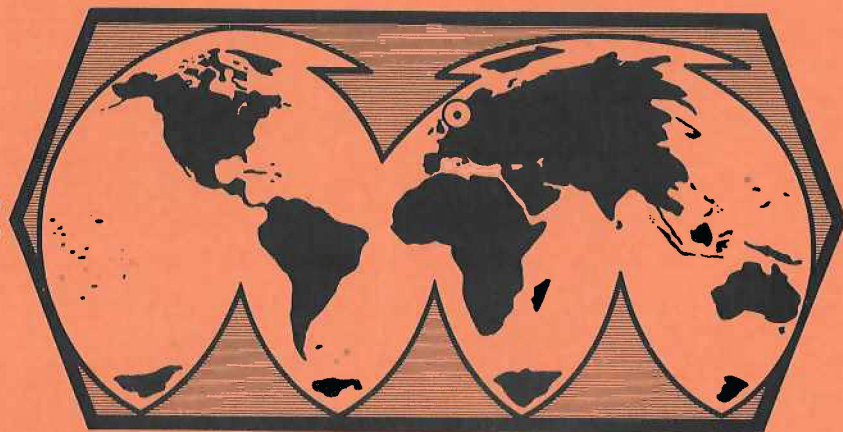
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E. P-WAVE AMPLITUDE VARIATIONS ACROSS NORSAR

It has been found that there is a large amplitude variation for P-wave signals crossing the array, and that this variation approximately follows a lognormal distribution (Ringdal et al 1972). The purpose of this study has been to measure these variations, and to find to what degree they influence the performance of the Detection Processor (DP). The data used has been established by measuring subarray and array beam amplitudes on P-phases detected at NORSAR during 1972 and 1973. All events which were not clipped and had a signal-to-noise ratio (SNR) above 6.5 have been used. Totally this gave 964 events. In Table E.1 is listed for each DP beam (Anonymous 1973) where any data is found and the amplitude loss for the different subarrays relative to the best subarray. The last row in Table E.1 gives the average performance for all beams. As seen from the table, the array beam amplitude has also been calculated and compared with the best subarray. This makes it possible to calculate the average signal correlation (ρ_s) between the different subarrays, when one assumes that the array beam loss is caused solely by lack of correlation. With the ρ_s value known and with the additional assumption that the noise is uncorrelated from one subarray to another, it is possible to calculate expected SNR loss on the array beam for the case where one or more subarrays are excluded from the beamforming. The procedure has been for each beam to calculate the expected SNR when only the subarray with the smallest amplitude is excluded, when the one with second smallest is also excluded, and so on until only the subarray with the highest amplitude is left. It is found that for more than 90% of the DP beams three or more subarrays could be excluded without decreasing the SNR on the beam. For 20% of the beams, ten or more subarrays could be excluded. There is, however, very seldom any significant gain in SNR obtained by deleting the subarrays with smallest amplitude. Only for 5% of the DP beams is it possible to obtain an SNR gain of 0.4 dB or more,

while for 23% of the cases a gain of 0.2 dB or more is possible. Figure E.1 illustrates a case where a gain of 0.15 dB can be obtained by deleting 9 subarrays, while Figure E.2 illustrates a case where no gain is obtained. As can be seen from Table E.1 the amplitude pattern may vary very drastically from one beam to another. It is, for example, seen that the subarray which in average has smallest amplitude (no. 22) for beam 11 and beam 13 is the very best subarray (both beams are pointing towards southeastern Alaska).

Figure E.3 shows the expected average performance if one permanently excludes a certain number of subarrays. Because of the varying amplitude pattern, it is seen that as an average one is always going to have a certain loss even by excluding only the very worst subarray. Excluding only no. 22 would, for example, in this case give a loss of 0.1 dB. If both no. 22 and no. 6 (the one with the second smallest amplitude) are excluded, one is on an average going to have a loss of 0.2 dB in detectability. Excluding half of the subarrays is going to give a loss of 1.9 dB in average, but for some particular regions this would, of course, have a much worse effect.

The two main subjects left to analyze in this work are the effect of varying signal correlation and the possibility that the amplitude pattern varies as a function of magnitude. Also figures like Figure E.3 are to be established for several regions.

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REFERENCE

Anonymous (1973): System Operation Report, NOR SAR Technical Report No. 62, NTNF/NORSAR, Kjeller, Norway, 20-24.

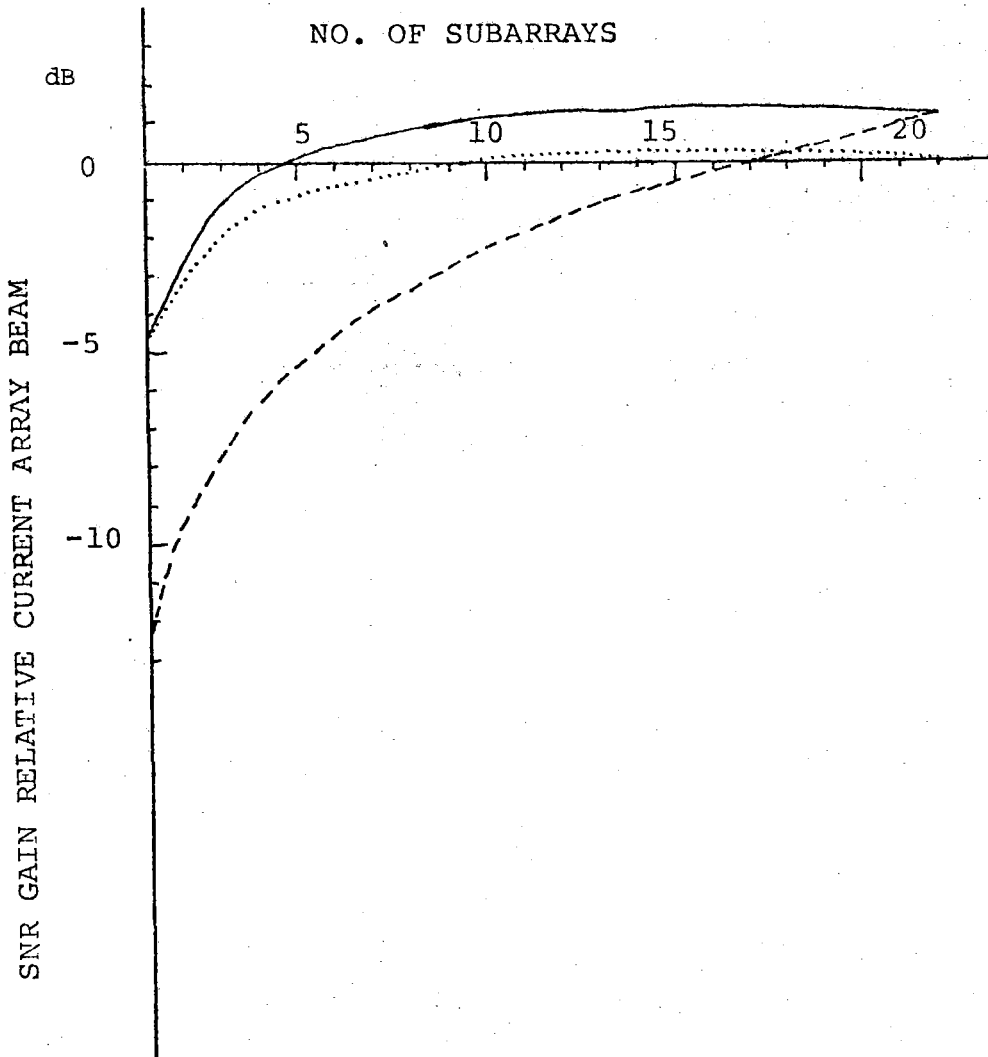


Figure E.1 Expected performance for beam 91 as a function of number of subarrays.

Beam 91 is steered towards South of Honshu, Japan (29N, 139E). The dashed line shows the theoretical \sqrt{N} signal-to-noise performance for the case that all signals are equal in shape and amplitude. This line ends at a gain of 1.2 dB, which implies that the currently used array beam has an average amplitude loss of 1.2 dB. The fully drawn line shows the performance if all signals were equal in shape (correlation=1.0) but had the amplitude pattern listed for beam 91 in Table 1. It is seen that the best subarray is only 4.5 dB below the current array beam. In this case a beam made from the 5 best subarrays is seen to give the same SNR as the current array beam. The dotted line shows the expected pattern and with an average signal correlation of 0.75. In this case the 10 best subarrays will give the same SNR as the beam. Using the 15 best subarrays is going to give a gain of 0.15 dB.

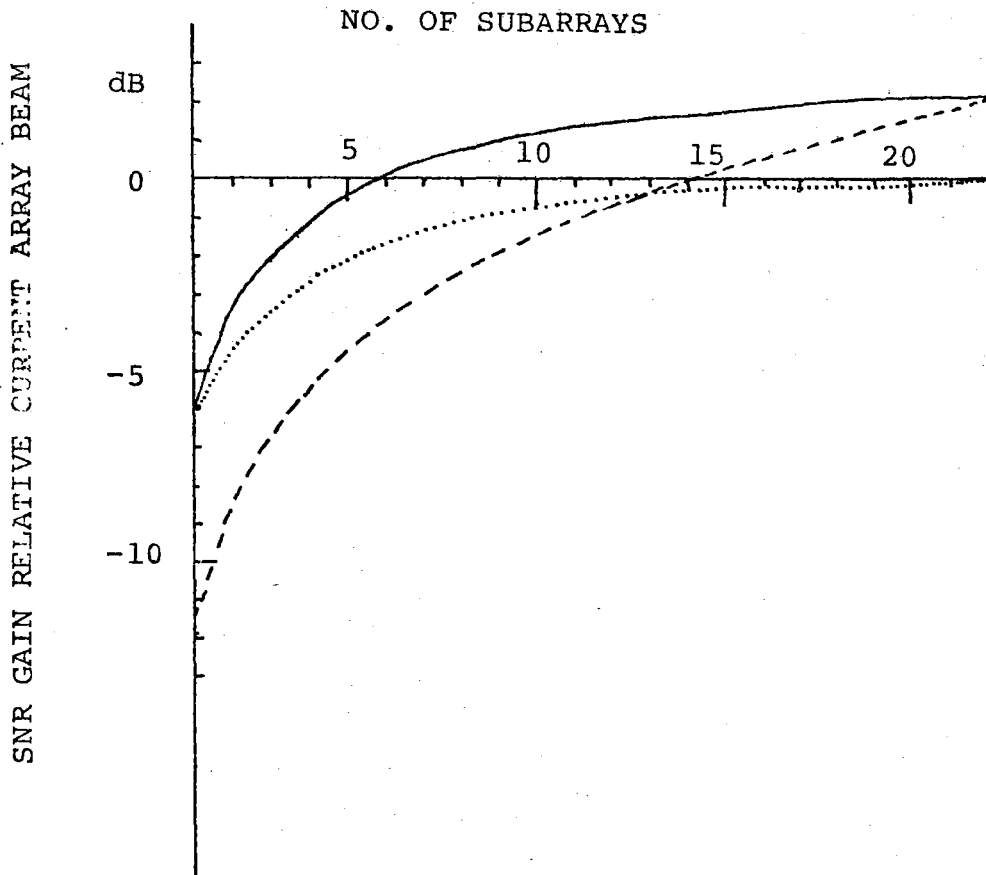


Figure E.2 Same as Figure E.1 for beam 175 pointing towards northern Colombia (7N, 73W). In this case the difference in amplitude between the best and the worst subarray is 10 dB (for beam 91 it is 17.7dB) and it is seen that no gain is obtained by excluding the bad subarrays.

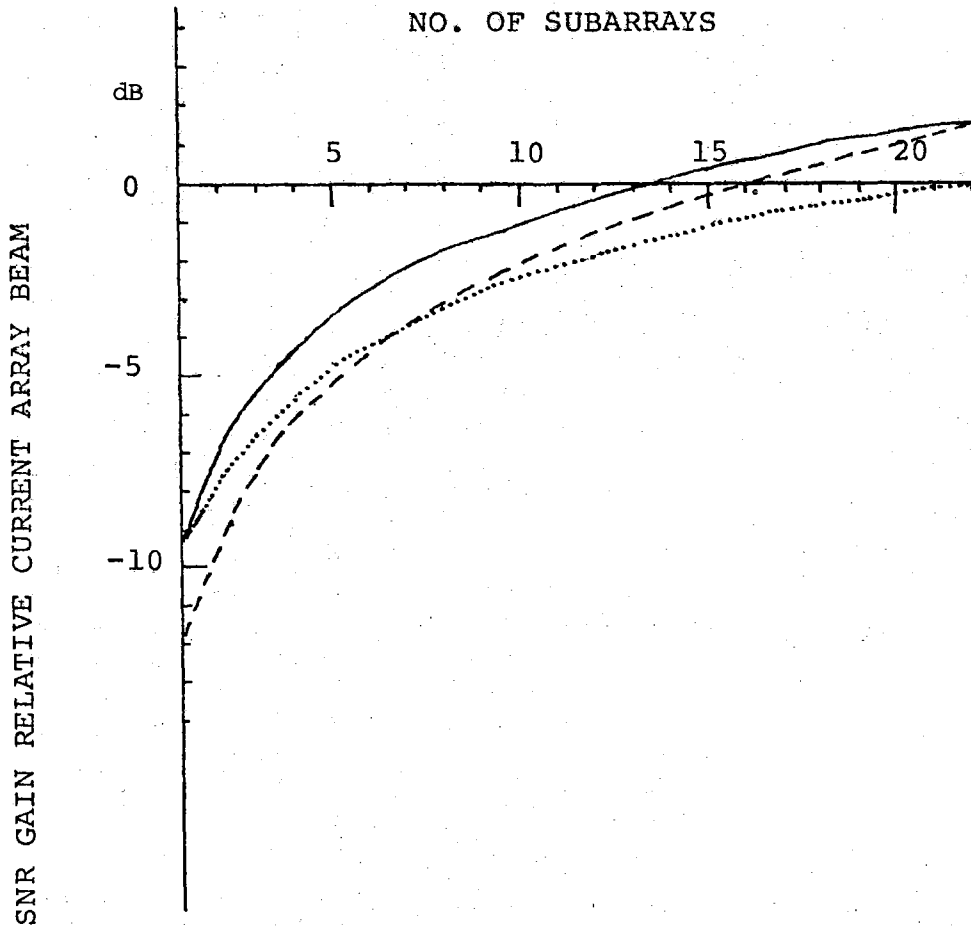


Figure E.3 Same as Figure E.1 for the average of all beams (last row Table 1). In this case the difference in amplitude between the best (no. 13) and the poorest (no. 22) subarray is only 4.5 dB, and it is seen that the observed performance gets closer to the theoretical \sqrt{N} performance. If only the 11 best subarrays were used, the average amplitude loss is seen to be 2.1 dB.

BEAM NO.	SUBARRAY NUMBER																						AB
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
6	3	9	5	10	13	10	3	4	5	12	9	2	0	9	5	8	8	10	8	8	8	8	
9	2	6	3	9	11	8	1	5	4	8	6	3	1	12	5	6	7	10	12	5	5	4	7
11	1	7	5	9	6	9	7	5	5	5	4	5	4	12	10	4	7	8	7	5	9	0	8
12	0	5	6	12	10	6	2	6	8	7	8	4	0	12	8	5	6	12	11	4	8	1	7
13	3	9	6	13	8	9	9	6	7	8	7	8	5	12	12	7	7	9	8	5	10	0	9
15	1	7	6	11	11	7	3	3	8	6	7	4	2	9	2	3	7	10	10	6	7	4	7
16	3	10	8	11	11	11	0	6	3	4	5	5	4	7	6	3	4	7	5	10	7	6	8
17	0	8	8	17	10	7	6	8	8	6	7	4	2	9	3	2	8	8	12	8		6	8
20	6	6	7	9	6	11	1	4	4	5	2	5	4	8	8	5	6	8	3	6	4	4	9
21	13	14	6	9	10	14	5	9	6	6	0	2	0	8	8	4	7	6	3	3	6	6	7
23	14	13	7	13	13	15	4	9	7	8	0	3	0	10	8	5	7	8	3	5	9	5	8
24	14	14	5	12	12	13	5	9	8	7	0	2	1	11	8	5	6	6	2	4	8	7	8
25	8	15	2	11	9	12	11	13	2	2	1	3	3	10	9	4	11	8	6	1	4	5	9
26	11	15	2	14	6	13	14	15	5	5	5	5	1	11	9	10	11	12	15	2	6	6	9
27	9	11	3	8	7	8	12	13	1	2	3	4	1	10	11	11	11	14	12	3	3	6	8
29	5	8	0	2	10	10	9	15	5	7	3	8	6	11	14	11	3	13	15	11	5	9	9
31	13	15	4	10	6	13	14	15	3	5	6	6	1	11	9	8	10	13	13	3	6	7	10
32	9	13	4	10	5	10	12	16	3	8	3	4	0	8	7	6	8	13	11	4	5		8
33	8	10	3	6	4	8	14	14	3	3	4	2	1	10	8	8	6	13	13	4	4	15	9
34	6	11	0	2	9	9	13	19	3	0	3	5	4	10	14	9	8	14	17	9	6	9	9
35	8	13	1	4	4	5	10	15	3	1	2	1	1	9	11	8	9	14	14	6	3	7	7
36	5	9	0	3	12	12	8	14	3	6	4	8	9	13	14	13	2	10	16	13	7	11	9
37	5	9	0	1	10	10	8	18	4	5	4	9	7	14	16	12	0	9	16	13	6	11	8
42	7	7	1	5	11	11	6	10	3	5	2	5	6	11	9	10	2	9	13	12	8	11	9
43	7	7	1	6	10	12	4	10	2	4	4	5	5	11	9	10	1	6	12	10	7	9	8
48	3	4	8	4	9	6	7	3	4	6	2	11	10	6	8	9	8	0	9	6	10	8	8
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52	10	13	1	6	9	14	9	13	8	9	5	5	0	10	11	11	11	9	14	15	16	17	11
53	8	8	0	8	11	13	6	12	7	10	7	5	2	12	15	14	12	6	13	13	15	17	11
55	14	10	9	0	11	18	16	10		15	6	16	16	8	10	11	15	10	13	15	14	18	12
56	9	7	8	1	6	7	11	7	8	9	1	13	6	0	5	7	5	3	12	8	8		9
58	9	10	0	8	10	14	8	14	9	10	8	4	2	13	16	14	13	7	14	14	17	18	11
60	8	6	9	0	15	5	12	2	4	10	2	6	2	1	3	8	6	11	14	8	10	11	9
62	8	7	8	0	12	16	12	12	9		5	18	15	10	8	7	11	8	9	15	15	17	10
63	8	8	1	9	12	15	7	12	7	8	7	6	4	15	17	14	14	5	13	12	16	15	11
64	7	4	0	8	12	15	6	8	3	6	3	5	3	14	16	14	11	3	12	9	16	11	9
65	8	1	2	10	9	14	8	3	0	2	1	7	2	13	12	14	9	2	8	2	8	4	8
70	8	4	2	9	10	13	7	4	1	1	4	4	3	12	12	9	9	5	9	7	14	12	8
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73	6	6	6	0	8	9	7	4	6	10	7	12		6	6	3	1	2	8	8	6	8	8
74	8	8	7	0	10	8	7	8	8	8	6	8	9	8	10	7	6	4	7	8	6		10
75	9	6	6	11	11	14	8	7	0	4	9	6	2	14	12	12	9	7	10	7	15	12	9
76	9	6	7	11	11	15	8	6	1	5	9	6	1	15	12	13	10	9	10	8	16	14	9
77	16	9	2	3	7	12	15	9	5	11	7	7	0	12	5	15	9	12	14	9		14	12
78	9	7	7	12	10	13	9	6	0	3	9	5	3	14	12	12	10	12	11	10	13	14	10
79	16	12	10	15	16	16	12	9	0	5	14	6	2	18	15	17	13	14	12	9	15	18	12
80	12	8	9	13	10	15	10	7	0	4	10	7	3	15	13	13	12	13	12	11	13	15	11

Table E.1 (Sheet 1 of 4)

Average subarray and array beam (AM) amplitude loss in dB for all NORSAR Detection Processor (DP) beams for which data were available. Information about the different beams is to be found in Anonymous (1974).

BEAM NO.	SUBARRAY NUMBER																						AB
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
81	14	13	7	9	16	21	15	10	5	10	7	5	0	14	17	15	16	12	12	13	15	14	
83	7	4	8	0	8	7	5	2	7	9	6	13	9	10	5	4	1	1	2	7	2	8	
84	9	9	7	11	8	12	8	5	0	2	7	6	3	13	12	13	12	12	11	10	12	13	10
86	13	10	10	14	9	10	11	7	0	6	10	5	1	14	10	13	11	13	10	11	13	18	11
87	13	9	8	12	12	14	10	8	3	8	6	4	0	15	13	17	14	17	8	12	11	16	11
89	8	8	10	11	7	10	11	0	5	8	8	7	11	8	7	8	8	7	7	11	6	12	11
90	6	7	8	13	7	14	9	1	1	3	4	4	7	8	9	10	10	5	5	12	8	12	9
91	7	6	5	13	7	13	10	6	2	3	7	2	0	13	11	14	12	11	10	12	14	18	9
92	7	7	4	10	6	10	8	2	1	3	7	1	2	9	11	11	13	9	7	12	10	13	8
93	12	8	4	7	12	17	11	5	2	6	4	0	1	14	12	13	8	15	6	3	6	14	9
95	9	2	3	0	1	11	3	7	11	7	7	10	8	9	11	6	4	1	4	9	5	5	7
97	10	8	5	12	11	13	12	6	0	5	3	3	1	12	9	11	9	13	6	10	2	10	9
98	8	6	6	9	9	12	9	3	1	4	4	2	3	11	10	10	8	12	4	10	6	13	9
101	9	8	2	3	3	7	2	6	12	14	8	10	4	13	8	6	4	3	1	5	2	4	7
102	10	3	3	2	1	9	3	8	10	10	7	12	7	9	9	5	5	1	1	10	3	3	7
103	8	12	5	10	9	11	10	6	1	10	4	4	0	9	7	10	9	11	4	9	1	11	9
104	0	4	3	3	6	2	3	8	11	9	6	4	1	1	13	8	7	10	7	3	8	7	6
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106	9	11	5	11	11	11	11	6	4	6	3	0	1	11	8	10	12	12	8	15	3	12	10
107	9	13	5	11	11	13	10	7	3	7	3	2	0	10	6	10	11	15	6	11	2	12	9
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116	9	13	11	14	11	14	12	7	13	6	3	0	4	14	9	7	12	11	7	13	4	12	11
119	3	8	5	6	6	3	4	9	9	9	11	5	4	0	10	6	4	10	7	1	5	6	9
120	7	12	10	11	9	12	7	5	4	3	3	4	8	11	6	6	12	5	3	7	0	7	9
121	5	10	10	10	9	10	8	4	3	4	4	3	8	11	7	5	12	7	3	8	2	10	9
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123	7	12	3	6	5	12	11	10	0	2	9	5	6	1	3	7	6	3	3	12	8	8	7
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142	8	3	5	5	7	5	2	4	3	3	8	2	0	5	9	3	3	0	5	8	6	5	
143	5	10	7	11	9	9	6	9	2	2	2	5	8	5	0	8	4	11	11	14	7	9	

Table E.1 (Sheet 2 of 4)

BEAM NO.	SUBARRAY NUMBER																						AB
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
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145	5	7	4	3	7	11	11	9	4	1	5	3	1	4	5	9	7	4	11	8	8	10	9
148	6	14	13	7	6	9	2	9	1	4	3	10	3	5	1	6	4	7	11	15	4	7	8
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152	10	5	9	7	10	2	1	4	10	6	10	6	7	5	10	0	4	8	12	1	10	13	7
155	6	12	7	5	4	7	0	7	2	3	1	8	2	5	4	4	7	6	10	6	3	7	7
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159	4	10	9	9	5	10	10	7	3	5	2	2	0	3	8	7	9	4	9	2	6	12	8
161	6	8	9	10	8	3	3	9	10	8	13	5	3	8	10	2	8	9	11	1	7	10	9
162	5	7	11	7	6	1	2	6	11	10	11	5	4	7	8	3	9	8	9	1	7	10	9
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165	8	6	10	6	5	9	6	7	9	5	7	8	7	5	6	3	10	10	11	2	2	10	10
166	10	11	10	4	5	5	6	6	7	6	5	6	1	3	2	2	6	8	10	0	3	8	7
167	10	6	12	9	5	7	5	6	7	5	8	8	5	4	6	3	13	9	12	0	2	9	8
168	11	6	9	5	5	5	3	5	6	10	3	8	1	6	2	3	9	10	10	2	3	6	8
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179	12	9	7	5	15	11	15	8	4	8	0	8	6	13	9	15	16	11	11	4	12	15	10
181	7	9	0	4	4	13	2	9	10	10	5	6	8	6	10	9	7	8	9	7	8	7	7
182	5	9	8	11	7	6	1	3	11	9	10	9	6	8	8	3	4	2	6	5	8	10	8
183	15	6	5	5	10	12	14	9	4	4	1	7	4	14	7	14	15	13	8	4	11	15	10
184	16	7	6	4	13	9	19	9	5	9	0	11	5	14	4	12	13	14	17	6	11	15	11
186	3	0	1	7	1	6	4	7	9	6	3	2	6	3	9	4	11	0	6	4	8	2	5
187	11	3	5	3	8	8	10	6	6	4	2	2	1	11	6	11	13	7	4	2	8	15	9
188	14	6	8	8	15	14	16	11	5	5	0	11	7	16	9	15	17	16	12	5	11	14	11
189	2	2	5	7	4	9	8	10	8	5	0	6	4	5	10	10	16	1	6	4	5	8	8
190	7	4	11	8	5	14	13	11	13	9	8	0	6	5	9	7	14	7	12	10	11	10	10
191	3	8	10	7	7	4	3	0	6	6	6	8	6	8	8	5	6	6	12	6	6	11	8
192	13	6	9	9	11	12	16	12	6	7	0	9	4	14	10	11	13	15	12	9	9	14	11
195	17	4	12	12	7	11	15	12	5	7	0	6	3	8	9	10	14	18	11	9	6	16	10
197	10	2	6	8	4	6	6	9	4	5	0	6	4	6	9	5	9	5	3	5	2	8	8
198	7	12	16	9	5	3	4	2	5	9	17	17	15	11	16	5	2	0	5	8	1	9	9
202	17	3	7	8	3	3	7	13	9	5	3	5	8	3	9	6	3	3	0	8	6	8	8
203	3	3	5	5	1	6	9	8	10	2	0	1	2	3	6	3	8	11	7	13	11	6	12
210	15	12	12	13	8	10	6	6	10	8	13	16	14	8	12	9	11	0	9	12	13	8	10
213	7	5	9	2	0	4	5	4	11	8	8	6	2	1	5	2	1	2	2	8	5	11	6
215	13	7	11	5	5	9	6	5	9	6	11	11	13	8	12	7	8	0	9	12	12	6	11
220	5	6	6	1	4	5	6	9	11	8	6	3	3	4	7	3	3	3	5	6	6	8	7
221	6	9	10	4	8	10	7	14	10	8	3	0	4	9	7	6	6	5	9	6	9	8	9
222	12	4	9	11	2	3	8	7	12	16	14	10	9	10	5	12	0	3	6	6	4	12	14

Table E.1 (Sheet 3 of 4)

BEAM NO.	SUBARRAY NUMBER																						AB
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
223	4	6	6	0	7	6	5	14	9	13	10	1	0	6	5	6	6	6	6	5	10	6	9
224	3	5	5	1	7	9	5	12	10	10	9	3	2	9	9	9	7	8	7	6	6	7	9
226	7	8	4	1	7	6	4	11	14	12	9	1	1	11	11	8	6	4	5	5	5	9	7
227	5	3	2	3	5	15	5	15	13	11	9	2	1	10	0	3	8	9	9	10	9	8	9
229	7	5	13	9	3	10	6	1	13	13	16	10	7	5	8	0	1	4	4	6	6	1	9
230	8	9	15	8	2	11	5	2	14	17	13	9	7	4	8	2	0	3	2	14	7	4	9
231	7	8	10	8	10	11	9	14	11	12	11	7	13	15	13	11	3	0	9	6	3	11	10
232	5	6	4	3	7	8	4	12	11	10	9	1	6	13	10	10	4	1	6	4	3	9	8
233	5	8	13	7	4	8	5	0	10	14	13	9	9	4	13	4	2	8	7	11	9	6	9
235	9	8	8	0	7	11	7	9	8	7	14	6	5	10	10	6	12	13	6	5	4	9	8
236	8	12	19	12	10	11	11	11	15	13	15	10	17	11	14	13	3	0	8	8		14	13
243	12	0	17	11	4	6	10	11	7	3	5	7	5	8	3	6	8	6	14	8	9	14	10
250	4	3	6	2	3	6	6	3	4	8	10	14	4	3	6	0	1	3	1	3	4		8
254	7	4	7	5	13	11	3	7	12	5	2	3	12	10	11	8	7	6	1	9	9	10	10
255	9	8	10	12	10	16	11	7	10	1	1	11	11	11	3	10	11	5	1	6	8		12
256	4	4	2	0	11	9	7	11	4	7	7	10	10	8	4	6	9	12	9	15	8		9
258	10	3	8	9	7	12	0	1	4	2	0	10	8	7	2	5	7	2		4	6	9	7
259	4	3	1	0	6	5	5	8	8	9	5	8	4	5	5	3	7	10	8	9	5	8	8
262	2	2	0	9	4	3	5	3	3	5	9	3	8	6	5	2	6	11	9	3	3	2	8
263	3	9	4	4	3	8	8	11	2	7	9	5	7	10	3	5	11	12	10	6	15		11
269	9	9	2	2		5	9	9	5	7	7	5	5	2	1	3	0	3	11	8	6	6	12
276	3	6	6	8	2	4	2	4	6	9	7	4	7	8	4	0	10	9	8	5	9	5	15
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285	8	8	11	7	8	8	13	11	8	9	5	0	2	4	12	5	8	13	7	15	9	7	13
286	7	10	5	7	11	3	9	5	14	13	1	9	14	7	12	3	6	7	8	9	3	9	9
287	5	11	4	5	9	2	10	4	16	15	4	10	14	5	10	5	5	6	6	9	3	12	9
288	11	9	8	8	14	3	13	7	14	15	0	14	16	7	13	3	9	9	6	13	2	8	10
289	10	8	8	6	13	3	7	9	16	16	0	16	16	4	14	6	11	8	4	10	3	10	10
292	7	3	3	5	11	4	4	7	12	10	0	15	13	3	8	5	5	6	6	7	2	6	8
293	9	5	7	5	11	3	6	10	14	15	1	15	13	3	10	6	9	8	7	8	4	9	9
294	7	4	8	6	13	5	2	7	14	6	2	16	14	3	7	5	6	6	5	7	2	7	8
295	9	5	10	6	12	7	3	7	13	8	5	14	12	4	8	7	4	7	5	5	0	6	9
300	12	13	6	2	8	3	8	9	11	14	9	13	4	1	11	0	3	5	3	12	15		7
303	9	11	0	4	6	7	3	6	7	5	11	13	5	9	10	7	6	9	5	4	3	7	8
304	8	10	2	3	8	9	5	7	6	5	9	9	6	10	11	9	9	11	6	7	4	5	10
305	8	9	0	3	5	6	7	3	3	1	10	11	4	9	9	6	5	9	7	1	7		7
311	7	10	10	0	2	4	4	9	7	8	6	2	1	4	14	0	9	4	4	10	7	7	7
312	12	10	9	0	7	8	7	9	5	5	4	3	6	6	10	7	7	5	4	9	7	1	8
313		12	7	5	3	4	9	7	4	4	0	3	3	2	8	5	3	7	4	8	8	7	8
315	5	7	6	9	10	8	13	0	7	4	10	11	9	8	8	9	5	10	10	10	2	13	8
316	10	7	6	7	11	1	10	6	12	10	1	11	14	5	7	3	4	6	6	10	4	11	11
217	6	13	14	8	3	9	5	6	6	6	4	0	11	3	17		6	7	4	4	10	10	9
318	0	10	7	7	12	6	13	6	13	11	10	10	14	8	14	10	6	10	5	11	5		10
	7	8	6	7	8	9	7	8	6	7	6	6	5	8	8	7	8	8	8	8	7	9	9

Table E.1 (Sheet 4 of 4)