Appendix A

Detailed Results

The full results for all the test problems are given below. The minimum, median, maximum, mean, and standard deviation values are given for all lumped, distributed, mixed lumped-distributed, and microstrip solutions.

The component ranges used are given in Table 3.3 on page 87 and the microstrip substrates used are given in Table 3.4 on page 87. The transmission line elements in the distributed results given below do not use the default parameters given in Table 3.3, but rather have the same parameters as the microstrip lines to allow comparisons between the ideal case and the case where dispersion and discontinuities are accounted for. The microstrip parameters were converted to characteristic impedances and line lengths using the low-frequency equations given in Sections 2.4.1 and 2.4.2 on pages 66 and 68. The ratios of the widths of microstrip lines at a discontinuity was limited to a maximum value of 5, and crosses were not allowed to ensure that the discontinuity calculations are accurate.

The mixed results do not consider discontinuities and dispersion for the transmission lines, and solder pads for the lumped components. These effects could have been included, but the inclusion of these effects would have dramatically increased the time to run the algorithm to closer to the time required for microstrip tests (see Section 4.4) without greatly adding

Table A.1: Problem 1 lumped results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	4.000	4.000	4.000	4.000	0.000
2	3.119	3.119	3.119	3.119	3.807×10^{-6}
4	1.601	1.602	1.607	1.602	1.210×10^{-3}
3	3.050	3.050	3.053	3.050	4.367×10^{-4}
5	1.527	1.539	1.575	1.541	1.156×10^{-2}
6	1.180	1.184	1.257	1.195	1.969×10^{-2}

Table A.2: Problem 1 distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.763	2.763	2.764	2.763	8.261×10^{-5}
2	1.641	1.652	1.692	1.654	1.114×10^{-2}
3	1.242	1.273	1.324	1.274	1.819×10^{-2}
4	1.089	1.156	1.258	1.159	3.449×10^{-2}
5	1.062	1.116	1.181	1.117	2.662×10^{-2}
6	1.048	1.090	1.146	1.090	1.895×10^{-2}

to the value of the results.

The microstrip networks can start with a parallel element because the algorithm assumes that all microstrip networks are bounded by 50 Ω transmission lines. This is necessary to complete the discontinuities (width steps or T-junctions) at the extremities of the networks.

Table A.3: Problem 1 mixed lumped-distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.763	2.763	2.764	2.763	1.375×10^{-4}
2	1.641	1.651	1.709	1.656	1.411×10^{-2}
3	1.245	1.285	1.347	1.285	2.339×10^{-2}
4	1.089	1.179	1.295	1.182	4.619×10^{-2}
5	1.077	1.134	1.204	1.133	3.145×10^{-2}
6	1.048	1.098	1.184	1.100	2.656×10^{-2}

Table A.4: Problem 1 microstrip results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.766 / 2.766	2.766 / 2.766	2.766 / 2.766	2.766	7.385×10^{-5}
2	1.644 / 1.653	1.656 / 1.660	1.704 / 1.657	1.659	1.097×10^{-2}
3	1.245 / 1.268	1.277 / 1.281	1.339 / 1.263	1.277	1.929×10^{-2}
4	1.090 / 1.182	1.186 / 1.179	1.273 / 1.243	1.180	3.900×10^{-2}
5	1.076 / 1.170	1.137 / 1.124	1.242 / 1.216	1.142	3.073×10^{-2}
6	1.057 / 1.107	1.107 / 1.084	1.225 / 1.155	1.108	2.438×10^{-2}

Table A.5: Problem 2 lumped results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	3.812	3.812	3.812	3.812	0.000
2	2.586	2.586	2.586	2.586	8.638×10^{-7}
3	2.222	2.222	2.222	2.222	7.199×10^{-5}
4	2.191	2.191	2.192	2.191	1.108×10^{-4}
5	2.099	2.102	2.106	2.102	1.262×10^{-3}
6	2.099	2.102	2.106	2.102	1.396×10^{-3}

Table A.6: Problem 2 distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	3.813	3.813	3.813	3.813	0.000
2	2.637	2.642	2.658	2.643	4.320×10^{-3}
3	2.197	2.340	2.433	2.316	7.717×10^{-2}
4	2.130	2.244	2.344	2.246	4.072×10^{-2}
5	2.138	2.184	2.268	2.188	2.851×10^{-2}
6	2.089	2.150	2.218	2.154	2.102×10^{-2}

Table A.7: Problem 2 mixed lumped-distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	3.813	3.813	3.813	3.813	0.000
2	2.586	2.586	2.607	2.587	2.078×10^{-3}
3	2.189	2.222	2.587	2.251	8.575×10^{-2}
4	2.159	2.193	2.202	2.193	4.367×10^{-3}
5	2.053	2.118	2.201	2.134	3.652×10^{-2}
6	2.034	2.114	2.190	2.118	2.499×10^{-2}

Table A.8: Problem 2 microstrip results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	4.227 / 4.393	4.227 / 4.393	4.227 / 4.393	4.227	1.000×10^{-6}
2	2.199 / 7.334	2.433 / 16.35	3.300 / 52.51	2.478	2.120×10^{-2}
3	2.062 / 5.122	2.093 / 10.41	2.327 / 964.4	2.109	4.497×10^{-3}
4	1.861 / 4.123	2.065 / 11.04	2.140 / 109.6	2.051	4.998×10^{-3}
5	1.658 / 5.968	1.897 / 15.02	2.037 / 471.4	1.877	7.229×10^{-3}
6	1.433 / 6.202	1.654 / 13.81	1.934 / 374.7	1.648	8.432×10^{-3}

Table A.9: Problem 3 lumped results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.500	2.500	2.500	2.500	0.000
2	2.024	2.024	2.024	2.024	2.721×10^{-6}
3	1.676	1.676	2.024	1.680	3.473×10^{-2}
4	1.670	1.670	2.024	1.674	3.533×10^{-2}
5	1.586	1.586	2.024	1.591	4.374×10^{-2}
6	1.586	1.586	2.024	1.591	4.373×10^{-2}

Table A.10: Problem 3 distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.500	2.500	2.500	2.500	0.000
2	2.107	2.112	2.126	2.113	4.363×10^{-3}
3	1.779	1.848	2.020	1.855	4.341×10^{-2}
4	1.740	1.809	1.897	1.810	3.204×10^{-2}
5	1.742	1.787	1.861	1.790	2.688×10^{-2}
6	1.707	1.762	1.802	1.761	1.795×10^{-2}

Table A.11: Problem 3 mixed lumped-distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.500	2.500	2.500	2.500	0.000
2	2.024	2.024	2.025	2.024	1.811×10^{-4}
3	1.676	1.707	2.024	1.727	7.873×10^{-2}
4	1.670	1.692	1.815	1.696	2.586×10^{-2}
5	1.586	1.680	1.795	1.665	4.934×10^{-2}
6	1.586	1.674	1.784	1.661	4.749×10^{-2}

Table A.12: Problem 3 microstrip results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.575 / 2.706	2.575 / 2.715	2.577 / 2.720	2.576	2.321×10^{-4}
2	1.308 / 2.514	1.643 / 9.728	2.293 / 33.74	1.680	2.171×10^{-2}
3	1.230 / 2.811	1.467 / 13.29	1.883 / 82.14	1.466	1.121×10^{-2}
4	1.105 / 4.788	1.264 / 8.664	1.541 / 595.2	1.273	9.473×10^{-3}
5	1.064 / 4.161	1.220 / 12.78	1.414 / 129.2	1.221	7.225×10^{-3}
6	1.047 / 4.458	1.174 / 46.34	1.357 / 992.2	1.179	5.658×10^{-3}

Table A.13: Problem 4 lumped results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	24.47	24.47	24.47	24.47	0.000
2	5.940	5.940	5.940	5.940	3.744×10^{-5}
3	4.505	4.505	4.507	4.505	3.230×10^{-4}
4	2.987	2.988	2.996	2.989	1.867×10^{-3}
5	2.929	2.940	2.988	2.944	1.519×10^{-2}
6	2.850	2.932	2.988	2.935	2.119×10^{-2}

Table A.14: Problem 4 distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	8.487	8.488	8.492	8.488	9.110×10^{-4}
2	5.979	6.026	6.690	6.057	9.953×10^{-2}
3	3.902	5.229	5.912	5.151	0.4285
4	3.372	4.335	5.285	4.322	0.3991
5	3.064	4.166	4.467	4.074	0.3545
6	1.478	2.387	3.892	2.457	0.4206

Table A.15: Problem 4 mixed lumped-distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	8.487	8.491	8.616	8.497	1.929×10^{-2}
2	5.938	5.942	6.401	5.982	8.439×10^{-2}
3	3.912	4.505	5.251	4.385	0.2376
4	2.988	3.075	4.472	3.335	0.4096
5	2.653	2.997	3.903	3.084	0.2039
6	2.455	2.980	3.430	2.952	0.1710

Table A.16: Problem 4 microstrip results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	8.493 / 8.628	8.496 / 8.674	8.563 / 8.691	8.498	8.134×10^{-3}
2	3.759 / 10.97	4.059 / 154.7	4.673 / 825.0	4.076	0.2026
3	2.337 / 23.55	3.448 / 171.1	4.441 / 955.1	3.480	0.4811
4	1.607 / 13.11	2.463 / 190.8	3.610 / 816.7	2.476	0.4472
5	1.602 / 47.73	2.015 / 210.6	2.773 / 804.9	2.041	0.2467
6	1.269 / 49.83	1.708 / 251.9	2.324 / 952.7	1.713	0.2475

Table A.17: Problem 5 lumped results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.004	1.004	1.004	1.004	0.000
2	0.1942	0.1945	0.6953	0.2663	0.1738
3	8.508×10^{-2}	0.1441	0.1953	0.1521	2.948×10^{-2}
4	4.538×10^{-2}	0.1302	0.1589	0.1136	3.188×10^{-2}
5	4.401×10^{-2}	0.1213	0.1481	0.1061	3.358×10^{-2}
6	4.210×10^{-2}	0.1171	0.1453	0.1042	3.380×10^{-2}

Table A.18: Problem 5 distributed results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.023	1.029	1.050	1.031	6.857×10^{-3}
2	0.1003	0.1144	0.1878	0.1250	2.479×10^{-2}
3	8.192×10^{-2}	0.1046	0.1353	0.1048	1.126×10^{-2}
4	8.311×10^{-2}	9.830×10^{-2}	0.1259	9.988×10^{-2}	9.400×10^{-3}
5	8.072×10^{-2}	9.538×10^{-2}	0.1185	9.617×10^{-2}	7.095×10^{-3}
6	7.231×10^{-2}	9.062×10^{-2}	0.1033	9.112×10^{-2}	5.506×10^{-3}

Table A.19: Problem 5 mixed lumped-distributed results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.004	1.004	1.004	1.004	0.000
2	0.1003	0.1397	0.2199	0.1395	3.337×10^{-2}
3	8.796×10^{-2}	0.1021	0.1336	0.1039	1.050×10^{-2}
4	8.504×10^{-2}	9.675×10^{-2}	0.1200	9.776×10^{-2}	7.347×10^{-3}
5	7.333×10^{-2}	9.140×10^{-2}	0.1157	9.257×10^{-2}	6.243×10^{-3}
6	3.970×10^{-2}	8.914×10^{-2}	0.1062	8.892×10^{-2}	7.373×10^{-3}

Table A.20: Problem 5 microstrip results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.082 / 1.103	1.090 / 1.110	1.281 / 1.136	1.100	2.956×10^{-2}
2	0.0963 / 0.1220	0.1194 / 0.1502	0.1885 / 0.1903	0.1285	2.710×10^{-2}
3	0.0880 / 0.1089	0.1105 / 0.1285	0.1397 / 0.1565	0.1126	1.172×10^{-2}
4	0.0881 / 0.1046	0.1047 / 0.1163	0.1352 / 0.1636	0.1053	9.110×10^{-3}
5	0.0870 / 0.1030	0.1023 / 0.1162	0.1268 / 0.1448	0.1027	8.643×10^{-3}
6	0.0846 / 0.1017	0.0978 / 0.1150	0.1278 / 0.1336	0.0983	7.459×10^{-3}

Table A.21: Problem 6 lumped results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.012	1.012	1.012	1.012	0.000
2	0.6629	0.6629	0.6629	0.6629	1.191×10^{-6}
3	0.2688	0.2694	0.2964	0.2717	5.565×10^{-3}
4	0.1922	0.1942	0.2380	0.1966	7.565×10^{-3}
5	7.960×10^{-2}	0.1750	0.2046	0.1577	3.260×10^{-2}
6	7.366×10^{-2}	0.1229	0.1929	0.1237	2.587×10^{-2}

Table A.22: Problem 6 distributed results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.257	1.257	1.257	1.257	1.000×10^{-6}
2	0.6641	0.6682	0.6826	0.6690	3.643×10^{-3}
3	0.1990	0.2723	0.4101	0.2751	4.358×10^{-2}
4	6.513×10^{-2}	0.2289	0.3273	0.2297	4.484×10^{-2}
5	1.965×10^{-2}	8.883×10^{-2}	0.2402	9.854×10^{-2}	4.949×10^{-2}
6	4.916×10^{-3}	3.531×10^{-2}	0.1527	4.237×10^{-2}	2.629×10^{-2}

Table A.23: Problem 6 mixed lumped-distributed results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.012	1.012	1.012	1.012	0.000
2	0.3054	0.3344	0.6629	0.4312	0.1586
3	9.332×10^{-2}	0.2335	0.4957	0.2586	0.1351
4	5.942×10^{-2}	0.1524	0.2288	0.1544	4.813×10^{-2}
5	4.462×10^{-2}	0.1424	0.1983	0.1344	4.560×10^{-2}
6	2.173×10^{-2}	0.1123	0.1978	0.1155	4.694×10^{-2}

Table A.24: Problem 6 microstrip results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.546 / 1.535	1.546 / 1.536	1.578 / 1.541	1.548	4.829×10^{-3}
2	1.133 / 1.148	1.171 / 1.181	1.221 / 1.220	1.174	2.361×10^{-2}
3	0.3284 / 0.3726	0.4540 / 0.4700	1.0224 / 0.5806	0.4590	9.498×10^{-2}
4	0.2302 / 0.2855	0.3165 / 0.3578	0.4621 / 0.4773	0.3244	4.733×10^{-2}
5	0.0174 / 0.0870	0.1028 / 0.1420	0.3098 / 0.3288	0.1123	4.826×10^{-2}
6	0.0080 / 0.0183	0.0398 / 0.0721	0.1181 / 0.2135	0.0438	2.340×10^{-2}

Table A.25: Problem 7 lumped results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	0.9710	0.9710	0.9710	0.9710	0.000
2	0.9164	0.9164	0.9165	0.9164	1.609×10^{-5}
3	0.6282	0.6327	0.8579	0.6702	6.543×10^{-2}
4	0.3194	0.4859	0.7937	0.4967	9.413×10^{-2}
5	0.3166	0.4611	0.7700	0.4719	9.164×10^{-2}
6	0.3014	0.4581	0.7835	0.4530	9.235×10^{-2}

Table A.26: Problem 7 distributed results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	0.9752	0.9752	0.9776	0.9753	2.414×10^{-4}
2	0.5977	0.9490	0.9700	0.8743	0.1141
3	0.2673	0.3268	0.4411	0.3341	3.517×10^{-2}
4	0.2560	0.2955	0.3988	0.2983	2.380×10^{-2}
5	0.2513	0.2783	0.3225	0.2806	1.434×10^{-2}
6	0.2214	0.2625	0.2891	0.2608	1.060×10^{-2}

Table A.27: Problem 7 mixed lumped-distributed results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	0.9710	0.9710	0.9710	0.9710	0.000
2	0.6491	0.9119	0.9202	0.9087	3.082×10^{-2}
3	0.2791	0.3642	0.5018	0.3700	4.651×10^{-2}
4	0.2608	0.3074	0.4022	0.3074	2.688×10^{-2}
5	0.2442	0.2861	0.3390	0.2879	1.785×10^{-2}
6	0.2408	0.2770	0.3269	0.2785	1.746×10^{-2}

Table A.28: Problem 7 microstrip results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.543 / 1.575	1.543 / 1.576	1.543 / 1.578	1.543	8.492×10^{-5}
2	0.3879 / 0.3993	0.4260 / 0.4366	0.4872 / 0.4594	0.4257	1.983×10^{-2}
3	0.2636 / 0.2942	0.3263 / 0.3586	0.3994 / 0.4356	0.3261	3.423×10^{-2}
4	0.2496 / 0.2703	0.2886 / 0.3076	0.3462 / 0.4394	0.2902	2.083×10^{-2}
5	0.2474 / 0.2659	0.2771 / 0.3062	0.3270 / 0.3467	0.2786	1.687×10^{-2}
6	0.2041 / 0.2277	0.2558 / 0.2835	0.2778 / 0.3398	0.2547	1.140×10^{-2}

Table A.29: Problem 8 lumped results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.539	1.539	1.539	1.539	0.000
2	0.6429	0.6429	0.6429	0.6429	9.326×10^{-7}
3	0.5618	0.5618	0.5693	0.5622	1.013×10^{-3}
4	0.2990	0.3794	0.5611	0.3921	6.714×10^{-2}
5	0.2490	0.3367	0.4802	0.3374	3.945×10^{-2}
6	0.2449	0.3005	0.4640	0.3107	3.470×10^{-2}

Table A.30: Problem 8 distributed results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.155	1.155	1.204	1.160	9.891×10^{-3}
2	0.4911	0.4972	0.5069	0.4975	2.978×10^{-3}
3	0.2793	0.4905	0.5002	0.4515	5.681×10^{-2}
4	0.1493	0.3512	0.4953	0.3481	7.620×10^{-2}
5	0.1137	0.2471	0.3700	0.2497	6.000×10^{-2}
6	6.850×10^{-2}	0.1841	0.3166	0.1831	4.855×10^{-2}

Table A.31: Problem 8 mixed lumped-distributed results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.155	1.159	1.245	1.167	1.752×10^{-2}
2	0.4426	0.4991	0.5617	0.4967	2.021×10^{-2}
3	0.2381	0.4520	0.5026	0.4223	7.490×10^{-2}
4	0.1580	0.3494	0.4975	0.3520	8.718×10^{-2}
5	0.1179	0.2907	0.4808	0.2847	8.497×10^{-2}
6	9.805×10^{-2}	0.2451	0.4516	0.2522	8.230×10^{-2}

Table A.32: Problem 8 microstrip results (decibel error).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	1.683 / 1.687	1.683 / 1.687	1.800 / 1.763	1.690	2.134×10^{-2}
2	0.5281 / 0.5349	0.7159 / 0.7713	0.9223 / 0.8995	0.7157	6.611×10^{-2}
3	0.3673 / 0.5021	0.6094 / 0.6583	0.7139 / 0.8521	0.5884	6.924×10^{-2}
4	0.2419 / 0.3630	0.4817 / 0.5211	0.6227 / 0.7000	0.4675	0.1026
5	0.1210 / 0.2751	0.3281 / 0.3889	0.5654 / 0.6801	0.3380	8.827×10^{-2}
6	0.0967 / 0.2389	0.2304 / 0.3059	0.4620 / 0.5000	0.2324	6.538×10^{-2}

Table A.33: Problem 9 lumped results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	39.80	39.80	39.80	39.80	0.000
2	2.889	2.889	2.890	2.889	3.441×10^{-5}
3	2.617	2.617	2.834	2.622	2.849×10^{-2}
4	1.214	1.268	1.333	1.257	2.861×10^{-2}
5	1.096	1.171	1.259	1.178	2.900×10^{-2}
6	1.074	1.135	1.236	1.136	3.713×10^{-2}

Table A.34: Problem 9 distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.588	2.590	2.657	2.595	1.168×10^{-2}
2	1.823	1.895	2.397	1.926	0.1025
3	1.634	1.749	1.884	1.754	4.245×10^{-2}
4	1.377	1.619	1.845	1.611	8.635×10^{-2}
5	1.253	1.440	1.668	1.440	7.702×10^{-2}
6	1.162	1.372	1.538	1.371	6.435×10^{-2}

Table A.35: Problem 9 mixed lumped-distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.588	2.591	2.647	2.595	1.009×10^{-2}
2	1.820	1.945	2.470	1.980	0.1481
3	1.259	1.484	1.867	1.530	0.1838
4	1.136	1.331	1.702	1.349	0.1053
5	1.125	1.261	1.532	1.267	7.888×10^{-2}
6	1.109	1.213	1.408	1.224	6.576×10^{-2}

Table A.36: Problem 9 microstrip results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	5.962 / 6.316	5.963 / 6.361	6.145 / 6.406	5.966	1.925×10^{-2}
2	5.962 / 6.223	5.988 / 6.362	6.510 / 6.492	6.012	7.058×10^{-2}
3	3.026 / 4.378	4.683 / 4.962	5.484 / 5.754	4.685	0.3658
4	2.128 / 3.987	3.468 / 11.26	4.100 / 682.8	3.420	0.4272
5	2.051 / 3.099	3.023 / 10.81	3.784 / 266.5	3.044	0.3582
6	1.576 / 3.050	2.662 / 18.83	3.498 / 460.2	2.648	0.4027

Table A.37: Problem 10 lumped results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.513	2.513	2.513	2.513	0.000
2	2.225	2.225	2.354	2.231	2.430×10^{-2}
3	1.467	1.557	2.063	1.590	9.351×10^{-2}
4	1.403	1.423	1.773	1.451	6.378×10^{-2}
5	1.403	1.408	1.607	1.416	2.473×10^{-2}
6	1.403	1.407	1.481	1.410	1.135×10^{-2}

Table A.38: Problem 10 distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.319	2.319	2.319	2.319	7.145×10^{-5}
2	1.719	1.835	1.972	1.837	6.682×10^{-2}
3	1.427	1.551	1.711	1.554	6.313×10^{-2}
4	1.405	1.451	1.513	1.455	2.549×10^{-2}
5	1.370	1.431	1.470	1.431	1.672×10^{-2}
6	1.354	1.424	1.444	1.419	1.883×10^{-2}

Table A.39: Problem 10 mixed lumped-distributed results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.319	2.319	2.335	2.320	2.830×10^{-3}
2	1.701	1.832	1.989	1.842	8.269×10^{-2}
3	1.416	1.592	1.816	1.590	8.089×10^{-2}
4	1.404	1.460	1.563	1.466	3.523×10^{-2}
5	1.318	1.435	1.476	1.435	1.936×10^{-2}
6	1.288	1.429	1.461	1.426	1.951×10^{-2}

Table A.40: Problem 10 microstrip results (VSWR).

Solution Length	Minimum	Median	Maximum	Mean	Standard Deviation
1	2.319 / 2.322	2.319 / 2.322	2.319 / 2.322	2.319	5.171×10^{-5}
2	1.943 / 1.953	1.976 / 1.977	2.104 / 2.036	1.987	3.334×10^{-2}
3	1.604 / 1.680	1.807 / 1.832	1.964 / 1.987	1.799	7.480×10^{-2}
4	1.438 / 1.451	1.576 / 1.605	1.714 / 1.689	1.570	6.744×10^{-2}
5	1.425 / 1.429	1.490 / 1.513	1.593 / 1.578	1.496	4.093×10^{-2}
6	1.412 / 1.431	1.466 / 1.478	1.526 / 1.520	1.466	2.267×10^{-2}

Appendix B

Best Circuits

The best circuits obtained are given below. The number of elements used in the best circuits is the same as published results where available, and produces a VSWR of less than 1.5 or a gain error of less than 0.1 dB where published results are not available. Six element solutions are given where this is not possible. The only exceptions are the distributed solutions to Problems 2 and 3, the mixed solution to Problems 2, 3 and 4, and the lumped and mixed solutions to Problem 7, where adding extra elements has a small (< 5%) effect. All circuits are drawn with the source on the left and the load on the right.

The component ranges used are given in Table 3.3 on page 87, and the microstrip substrates used are given in Table 3.4 on page 87. The transmission line elements in the distributed results given below do not use the default parameters given in Table 3.3, but rather have the same parameters as the microstrip lines to allow comparisons between the ideal case and the case where dispersion and discontinuities are accounted for. The microstrip parameters were converted to characteristic impedances and line lengths using the low-frequency equations given in Sections 2.4.1 and 2.4.2 on pages 66 and 68. The ratios of the widths of microstrip lines at a discontinuity was limited to a maximum value of 5, and crosses were not allowed to ensure that the discontinuity calculations are accurate.

The mixed results do not consider discontinuities and dispersion for the transmission lines, and solder pads for the lumped components. These effects could have been included, but the inclusion of these effects would have dramatically increased the time to run the algorithm to closer to the time required for microstrip tests (see Section 4.4) without greatly adding to the value of the results.
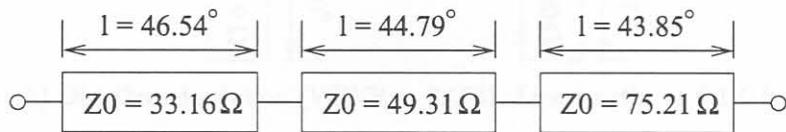
The microstrip networks can start with a parallel element because the algorithm assumes that all microstrip networks are bounded by 50 Ω transmission lines. This is necessary to complete the discontinuities (width steps or T-junctions) at the extremities of the networks.

(a) Lumped solution (VSWR = 1.180).

(b) Distributed solution (VSWR = 1.242). Line lengths at 2 GHz.
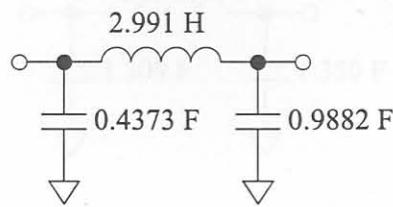
(c) Mixed solution (VSWR = 1.245). Line lengths at 2 GHz.
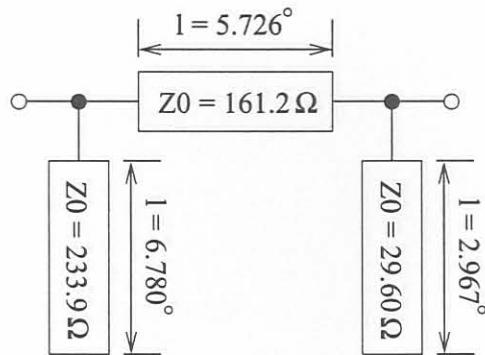
(d) Microstrip solution with $h = 0.25$ mm and $\varepsilon_r = 5$ (VSWR = 1.245).

## Figure B.1: Test Problem 1 solutions.

2.991 H

0.4373 F   0.9882 F

(a) Lumped solution (VSWR = 2.222).

l = 5.726°

Z0 = 161.2 Ω

Z0 = 233.9 Ω   l = 6.780°   Z0 = 29.60 Ω   l = 2.967°

(b) Distributed solution (VSWR = 2.189). Line lengths at 0.1 GHz.

l = 5.305°

Z0 = 171.2 Ω

3.044 pF

Z0 = 165.5 Ω   l = 5.828°
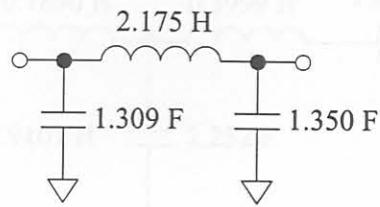
(c) Mixed solution (VSWR = 2.099). Line lengths at 0.1 GHz.

l = 269.0 mm   l = 294.1 mm   l = 176.3 mm   l = 83.03 mm   l = 122.9 mm

w = 5.087 mm   w = 7.956 mm   w = 9.000 mm   w = 26.66 mm   w = 5.463 mm

w = 8.800 mm   l = 6.000 mm
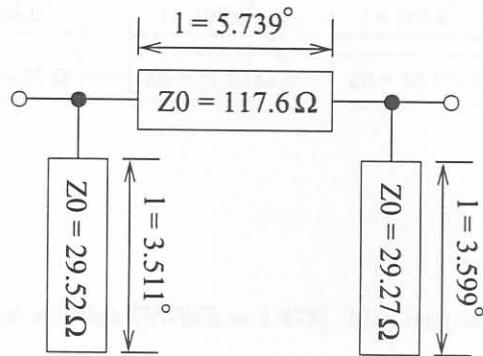
(d) Microstrip solution with $h = 3$ mm and $\varepsilon_r = 1$ (VSWR = 1.433).

Figure B.2: Test Problem 2 solutions.

2.175 H

1.309 F   1.350 F

(a) Lumped solution (VSWR = 1.676).

l = 5.739°

Z0 = 117.6 Ω

Z0 = 29.52 Ω   l = 3.511°

Z0 = 29.27 Ω   l = 3.599°
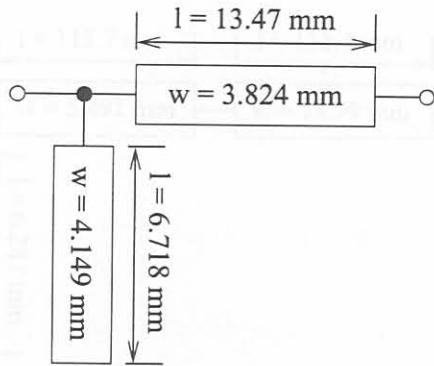
(b) Distributed solution (VSWR = 1.779). Line lengths at 0.1 GHz.

16.83 nH   19.23 nH

4.490 pF   4.734 pF   4.523 pF
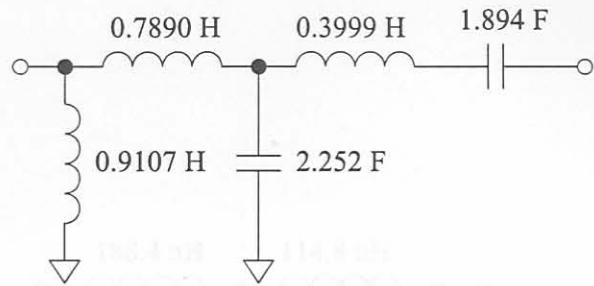
(c) Mixed solution (VSWR = 1.586). Line lengths at 0.1 GHz.

l = 13.47 mm

w = 3.824 mm

w = 4.149 mm   l = 6.718 mm
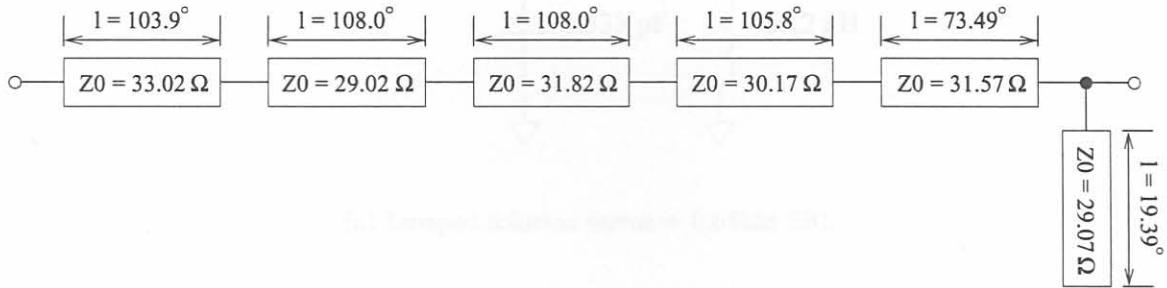
(d) Microstrip solution with $h = 3$ mm and $\varepsilon_r = 1$ (VSWR = 1.308).

Figure B.3: Test Problem 3 solutions.

0.7890 H   0.3999 H   1.894 F

0.9107 H   2.252 F

(a) Lumped solution (VSWR = 2.929).

l = 103.9°   l = 108.0°   l = 108.0°   l = 105.8°   l = 73.49°

Z0 = 33.02 Ω   Z0 = 29.02 Ω   Z0 = 31.82 Ω   Z0 = 30.17 Ω   Z0 = 31.57 Ω

Z0 = 29.07 Ω   l = 19.39°
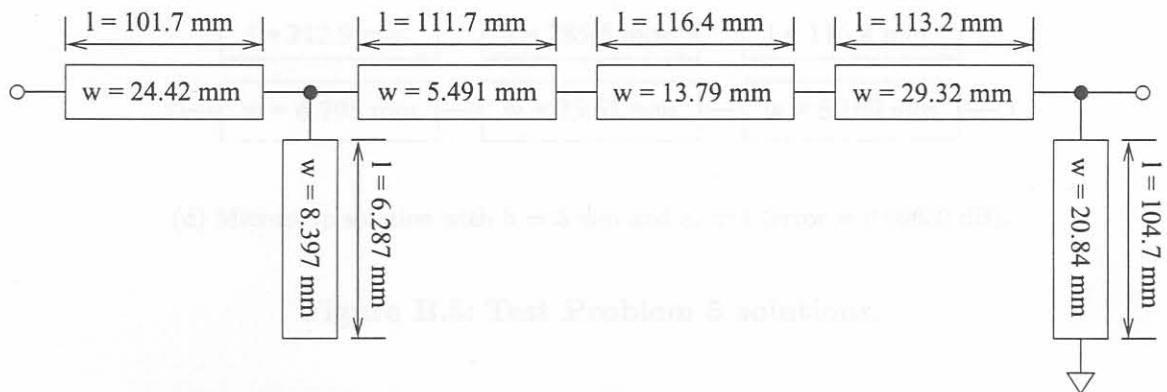
(b) Distributed solution (VSWR = 1.478). Line lengths at 0.3 GHz.

l = 50.48°   18.62 pF

4.026 nH   Z0 = 35.11 Ω

19.92 nH   Z0 = 217.0 Ω   l = 80.38°   Z0 = 104.7 Ω   l = 58.15°
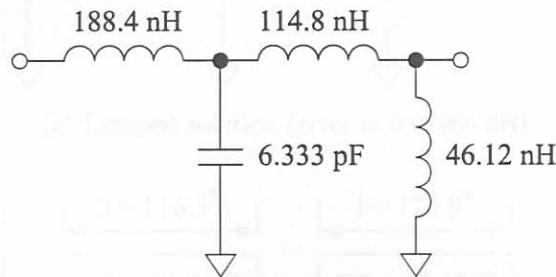
(c) Mixed solution (VSWR = 2.455). Line lengths at 0.3 GHz.

l = 101.7 mm   l = 111.7 mm   l = 116.4 mm   l = 113.2 mm

w = 24.42 mm   w = 5.491 mm   w = 13.79 mm   w = 29.32 mm

w = 8.397 mm   l = 6.287 mm   w = 20.84 mm   l = 104.7 mm
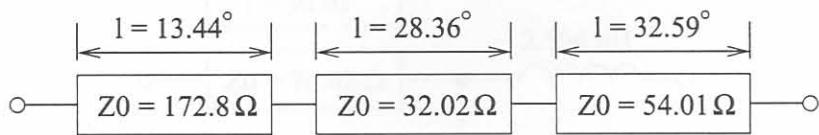
(d) Microstrip solution with $h = 3$ mm and $\varepsilon_r = 1$ (VSWR = 1.269).
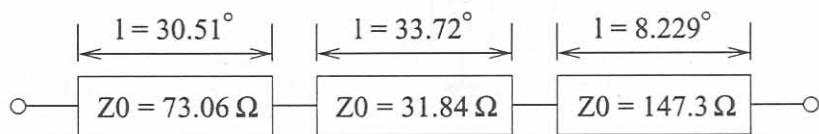
Figure B.4: Test Problem 4 solutions.
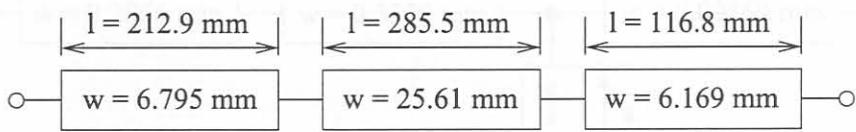
(a) Lumped solution (error = 0.04538 dB).

(b) Distributed solution (error = 0.08192 dB). Line lengths at 0.1 GHz.
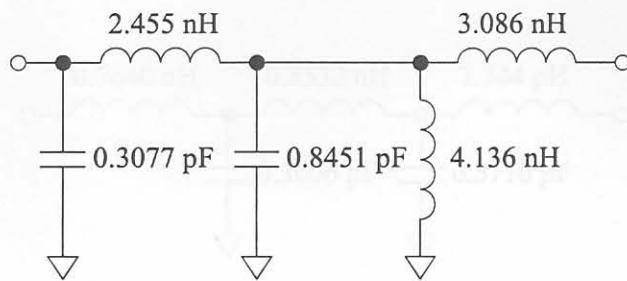
(c) Mixed solution (error = 0.08796 dB). Line lengths at 0.1 GHz.
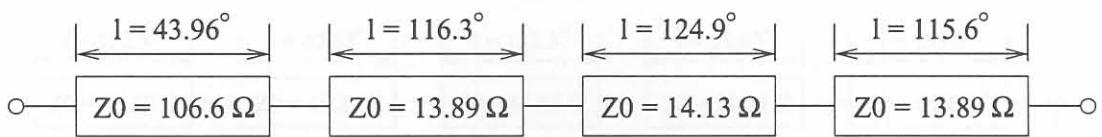
(d) Microstrip solution with $h = 3$ mm and $\varepsilon_r = 1$ (error = 0.09630 dB).
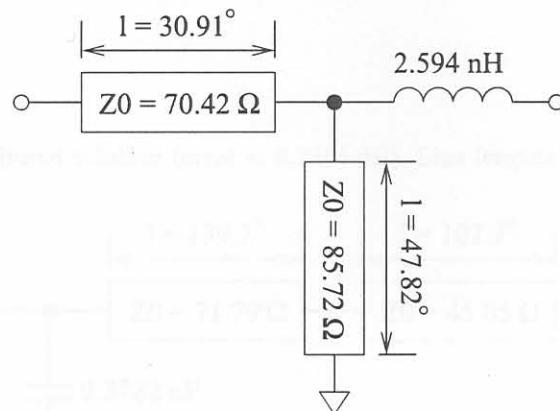
Figure B.5: Test Problem 5 solutions.

2.455 nH   3.086 nH

0.3077 pF   0.8451 pF   4.136 nH
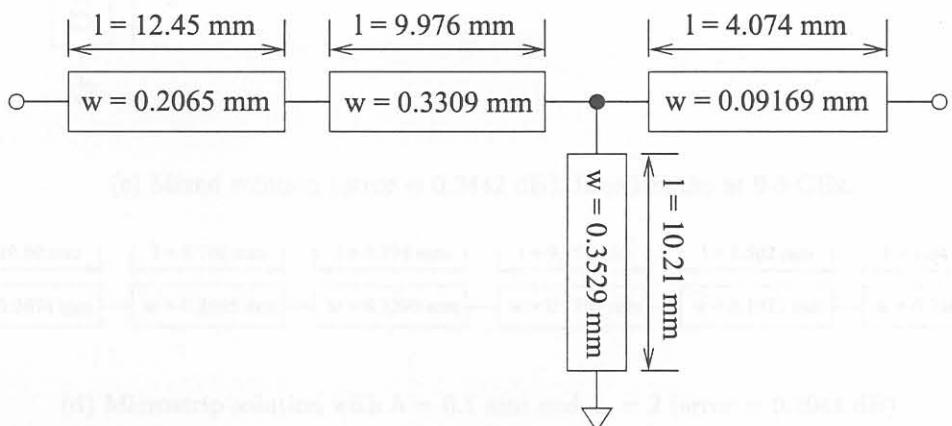
(a) Lumped solution (error = 0.07960 dB).

| l = 43.96° | l = 116.3° | l = 124.9° | l = 115.6° |
| Z0 = 106.6 Ω | Z0 = 13.89 Ω | Z0 = 14.13 Ω | Z0 = 13.89 Ω |

(b) Distributed solution (error = 0.06513 dB). Line lengths at 2 GHz.

l = 30.91°

2.594 nH

Z0 = 70.42 Ω

Z0 = 85.72 Ω

l = 47.82°
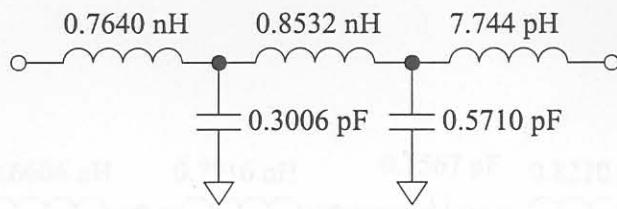
(c) Mixed solution (error = 0.09332 dB). Line lengths at 2 GHz.

| l = 12.45 mm | l = 9.976 mm | l = 4.074 mm |
| w = 0.2065 mm | w = 0.3309 mm | w = 0.09169 mm |

w = 0.3529 mm

l = 10.21 mm
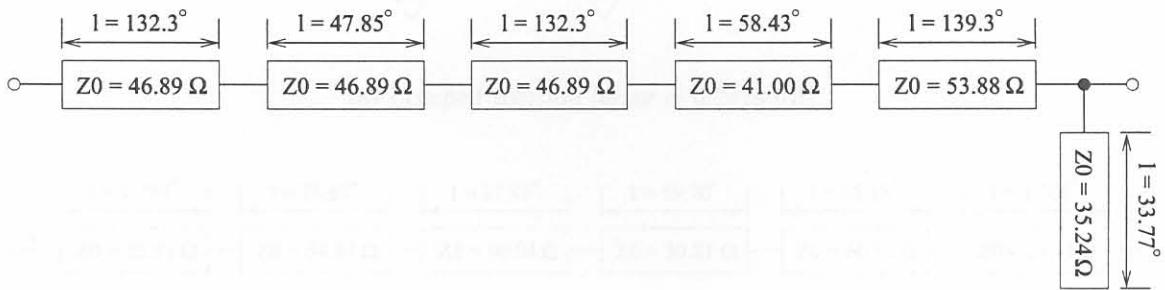
(d) Microstrip solution with $h = 0.25$ mm and $\varepsilon_r = 5$ (error = 0.01738 dB).
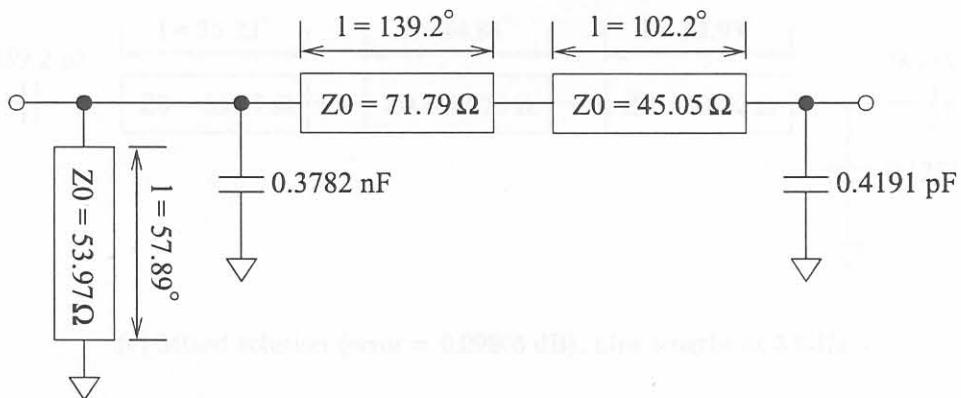
Figure B.6: Test Problem 6 solutions.

0.7640 nH   0.8532 nH   7.744 pH

0.3006 pF   0.5710 pF
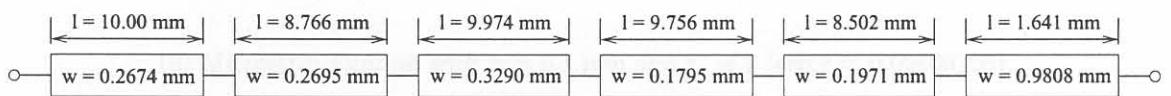
(a) Lumped solution (error = 0.3166 dB).

| l = 132.3° | l = 47.85° | l = 132.3° | l = 58.43° | l = 139.3° |
| Z0 = 46.89 Ω | Z0 = 46.89 Ω | Z0 = 46.89 Ω | Z0 = 41.00 Ω | Z0 = 53.88 Ω |

Z0 = 35.24 Ω   l = 33.77°

(b) Distributed solution (error = 0.2214 dB). Line lengths at 9.5 GHz.

l = 139.2°   l = 102.2°

Z0 = 71.79 Ω   Z0 = 45.05 Ω

Z0 = 53.97 Ω   l = 57.89°

0.3782 nF

0.4191 pF
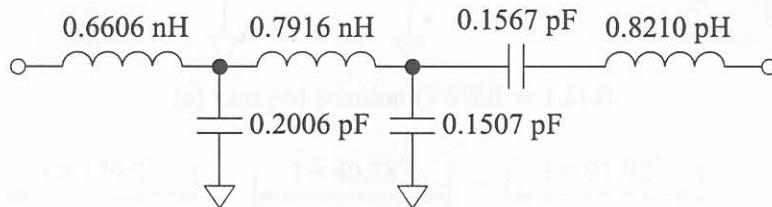
(c) Mixed solution (error = 0.2442 dB). Line lengths at 9.5 GHz.

| l = 10.00 mm | l = 8.766 mm | l = 9.974 mm | l = 9.756 mm | l = 8.502 mm | l = 1.641 mm |
| w = 0.2674 mm | w = 0.2695 mm | w = 0.3290 mm | w = 0.1795 mm | w = 0.1971 mm | w = 0.9808 mm |
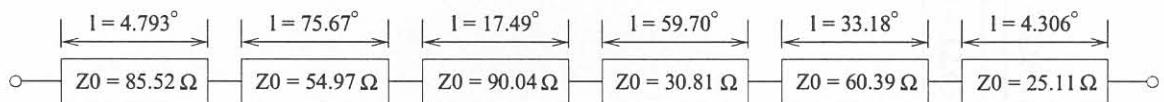
(d) Microstrip solution with $h = 0.1$ mm and $\varepsilon_r = 2$ (error = 0.2041 dB).
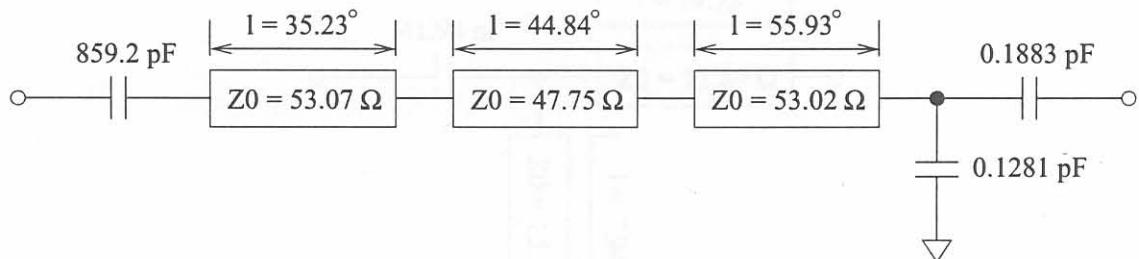
Figure B.7: Test Problem 7 solutions.
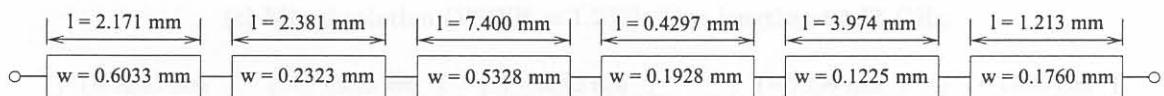
(a) Lumped solution (error = 0.2449 dB).

(b) Distributed solution (error = 0.06858 dB). Line lengths at 5 GHz.
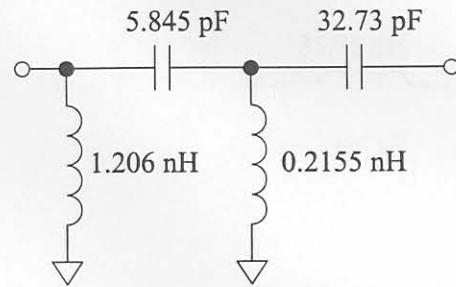
(c) Mixed solution (error = 0.09805 dB). Line lengths at 5 GHz.
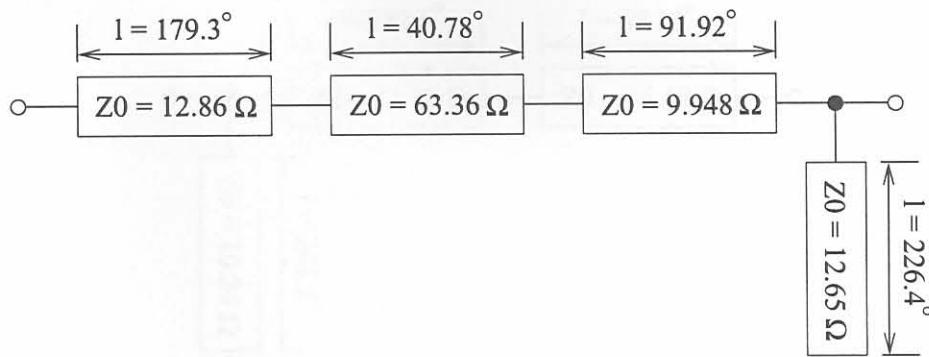
(d) Microstrip solution with $h = 0.1$ mm and $\varepsilon_r = 2$ (error = 0.09666 dB).
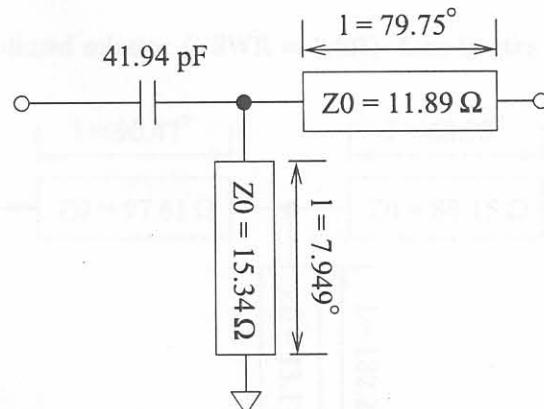
Figure B.8: Test Problem 8 solutions.
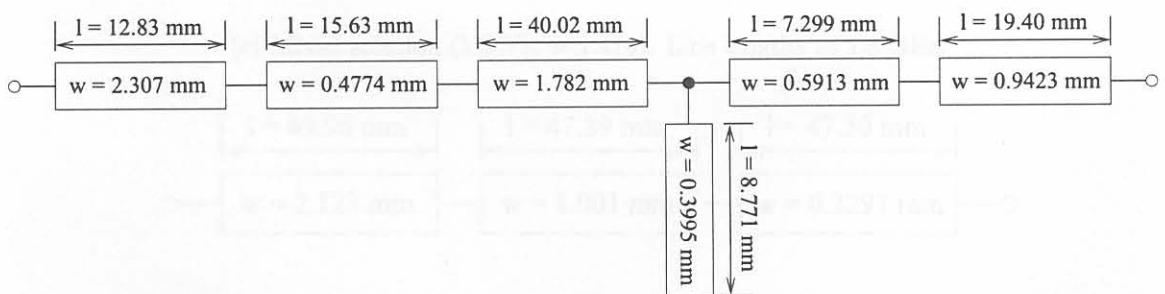
(a) Lumped solution (VSWR = 1.214).

(b) Distributed solution (VSWR = 1.377). Line lengths at 1.75 GHz.
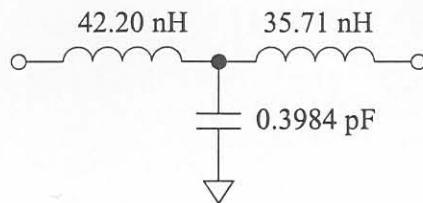
(c) Mixed solution (VSWR = 1.259). Line lengths at 1.75 GHz.
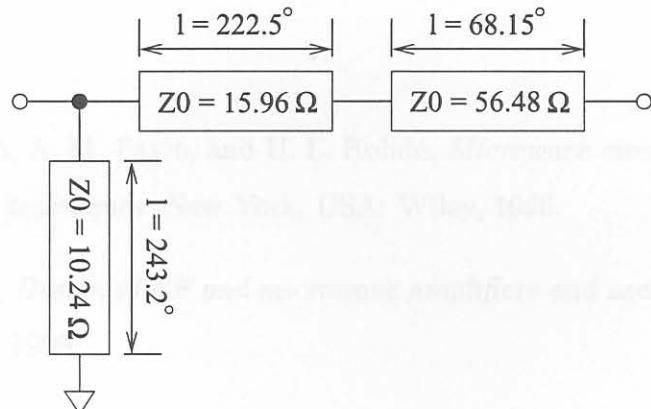
(d) Microstrip solution with $h = 0.5$ mm and $\varepsilon_r = 10$ (VSWR = 1.576).
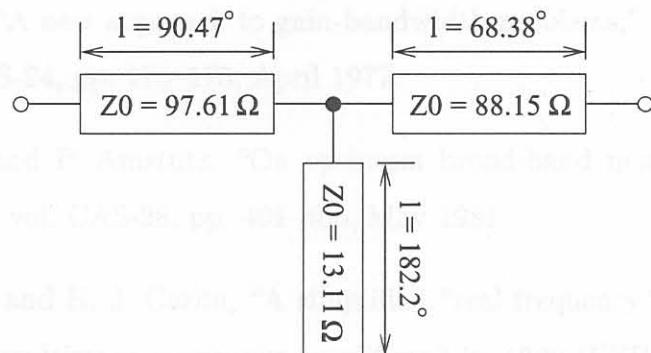
**Figure B.9: Test Problem 9 solutions.**
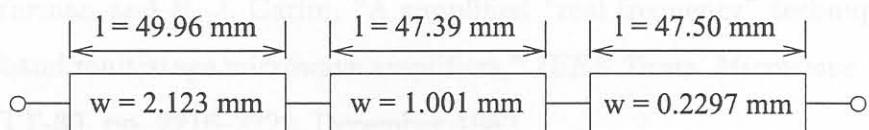
(a) Lumped solution (VSWR = 1.467).

(b) Distributed solution (VSWR = 1.427). Line lengths at 1.8 GHz.

(c) Mixed solution (VSWR = 1.416). Line lengths at 1.8 GHz.

(d) Microstrip solution with $h = 0.5$ mm and $\varepsilon_r = 10$ (VSWR = 1.604).

Figure B.10: Test Problem 10 solutions.