CHAPTER 6. SUMMARY AND CONCLUSIONS

Realising the shortfalls of conventional microwave differential phase shifters, an in-depth study was launched into this area, focussing on the synthesis of ultra-wideband devices covering up to more than a decade of bandwidth. This excluded ferrite, MMIC, waveguide and some other technologies which are relatively band-limited. By noting the unique and very valuable frequency independent quadrature property of symmetric couplers, a novel class of phase shifter is proposed. Realising that the phase shift characteristics can be related to the coupling characteristics of the coupler, considerable freedom with respect to bandwidth and ripple is achieved [1,2].

Firstly, the principle of operation of the novel class of phase shifter was discussed. It was compared to the classical wideband Tresselt [3] phase shifter, and the practical bandwidth-limiting obstacles were shown to be eliminated. The phase shifter was divided into three main elements, namely the splitter, impedance tapers and coupler. The elements comprising the phase shifter was then separately analysed and practically investigated. A unique splitter was developed to ensure phase and amplitude tracking at the coupler inputs [4]. Considerable attention was given to the analysis and synthesis of the splitter. The periodic broadside coupled stripline (BCS) structure was also fully analysed and the resonance nature of the structure was predicted. The through-hole plated vias in the BCS structure were analysed by both a full-wave analysis and a finite element analysis to compare the results. Empirical element fit was conducted to provide a future designer with very accurate via models. The splitter performance was then mathematically predicted and compared to a physical practical example. A tolerance analysis was also conducted on each element comprising the phase shifter, and this was compared to the phase shifter sensitivity analysis demands.

The phase shifter was then analysed thoroughly to determine its sensitivity with respect to errors due to manufacturing tolerances. Error and performance parameters were defined and sensitivities to tolerance variations were calculated. These results clearly demonstrate the practicality of the idea and also pinpoint the areas of the phase shifter most sensitive to tolerances. It was demonstrated that the performance of the phase shifter is sensitive to phase imbalance errors, and that application of symmetry enhancement techniques is important to attain the desired performance of ultra-high bandwidth devices. It was also demonstrated that the phase shifter is relatively insensitive to amplitude errors. It was discovered that the phase performance of symmetrical couplers was not significantly influenced by normal material tolerances. Scaling errors and over- or under-etching also did not unduly influence phase performance, but rotational alignment was found to be critical to the performance of the coupler. Restrictions to the theory were discussed and the manufacturing requirements were highlighted.

A general synthesis procedure was derived to aid in future designs. A computer program was written to fully design the tapered coupler from material and electrical specifications. The study ends with a design example, comparing analysis results with practical measured results. The results clearly indicates an excellent agreement between the analysis and measured performance, specifically demonstrated by the 45° phase shifter which proved to be the most sensitive to material and manufacturing tolerances. The practical measured results fall comfortably within expected production tolerance boundaries. At 45° nominal phase shift and a 5° Chebyshev ripple, a slightly larger bandwidth was achieved, and the phase shift attained the desired 5° ripple except for the first two ripple peaks which exceed the specification by approximately one degree.

It can therefore be concluded that a novel ultra-wideband class of phase shifter was found. It was demonstrated that this phase shifter can be practically implemented utilizing standard materials and processes. The design equations and practical implementation of this class of phase shifter were discussed and analysed in detail. It was also demonstrated that superior freedom with respect to bandwidth and ripple could be achieved, and the shortfalls of conventional wideband phase shifters can therefore be overcome.

References

[1] F.V.Minnaar, J.C.Coetzee, and J.Joubert, "The analysis and synthesis of a novel ultra - wideband microwave differential phase shifter," in IEEE AP MTT - Symp., Pretoria, S.A., pp. 138 - 433, Nov 1995.

[2] F.V.Minnaar, J.C.Coetzee, and J.Joubert, "A novel ultra - wideband microwave differential phase shifter, " IEEE Trans. Microwave Theory Tech., vol.45, pp. 1249 - 1252, Aug. 1997.

[3] C.P.Tresselt, "Broadband tapered - line phase shift networks, " IEEE Trans. Microwave Theory Tech., vol. MTT - 16, pp. 51 - 52, Jan 1968.

[4] F.V.Minnaar, J.C.Coetzee, and J.Joubert, "The development of an ultra - wideband via connected broadside coupled splitting structure, " in IEEE AP MTT - Symp., Cape Town, S.A., pp. 465 - 466, Sept. 1998.